Laboratory Environment Safety and Health Committee
Cryogenic Safety Subcommittee

MINUTES OF MEETING 03-11

December 19, 2003

FINAL

Committee Members Present
R. Alforque
W. Glenn
M. Iarocci
S. Kane
P. Kroon
E. Lessard (Chairperson)
R. Travis* (Secretary)

(* non-voting)

Committee Members Absent
P. Mortazavi
M. Rehak
A. Sidi Yekhlef
K. C. Wu

Visitors
S. Bellavia
C. Biggs
Y. Makdisi
E. O'Brien
R. Pisani
T. Shea

Agenda:

1. **PHENIX TEC/TRD - Review of the Proposed Pressure Increase for the Xenon Recovery System**

Minutes of Meeting: Appended on pages 2 through 3.

ESH COMMITTEE MINUTES APPROVED:

_Signature on File_________________ ____________________________________
E. Lessard **Date** **J. Tarpinian** **Date**
LESHC Chairperson **ESH&Q ALD**

Chairperson Ed Lessard called the eleventh meeting in 2003 of the Laboratory Environmental Safety and Health Committee (LESHC) to order on December 19, 2003 at 1:30 p.m.

1. **PHENIX TEC/TRD - Review of the Proposed Pressure Increase for the Xenon Recovery System:** Ed O'Brien and Peter Kroon presented the proposed pressure increase for the Xenon Recovery System associated with the PHENIX Time Expansion Chamber/Transition Radiation Detector [1].
   - 1.1. E. O'Brien, P. Kroon and other attendees made the following points during the course of the presentation and in response to specific Committee questions:
     - 1.1.1. PHENIX plans to operate the TEC/TRD with a xenon gas mixture. This gas mixture is very expensive and a recovery system has been installed to allow capture and recirculation of the xenon.
     - 1.1.2. The Xenon Recovery System is located outdoors on the gas pad near Bldg. 1008. As such, there are no ODH concerns.
     - 1.1.3. The Recovery System has two custom made cryostats that function as cold traps and fill with liquid xenon. (The cryostats are normally used one at a time.)
     - 1.1.4. Each cryostat is a double walled vessel with an annular vacuum space.
       - 1.1.4.1. The inner vessel collects the xenon in liquid/solid form. It has a volume of about 10 liters and is protected by a relief valve, set at 1 psig.
       - 1.1.4.2. The inner vessels were proof tested to 2 atmospheres.
       - 1.1.4.3. The vacuum space has a volume of about 25 liters. It is protected by a 1 psi rupture disk, sized for twice the expected flow from an inner vessel failure.
     - 1.1.5. When a cryostat is full, it is isolated from the system. The second unit is then put in service to allow continuous xenon recovery.
     - 1.1.6. The liquid/solid xenon "slush" in the full cryostat is evaporated. The resulting pressure allows cold xenon gas to be transferred to a steel storage cylinder.
     - 1.1.7. Prior to the merger with the LESHC, the BNL Cryogenic Safety Committee (CSC) had reviewed and approved the Xenon Recovery System operation at 1 psig[2] in its January 24 and April 3, 2003 meetings[1]. It was noted that because of its small size, the inner vessel is not subject to the ASME Boiler Code requirements.
     - 1.1.8. During system commissioning at 1 psig, the PHENIX Group found that the backpressure (caused by the vaporizing gas in the heat exchanger) prevented xenon transfer to the storage cylinder.
     - 1.1.9. The commissioning process established that a <u>maximum</u> system operating pressure of 10 psi (24.7 psid) would enable xenon flow into the storage cylinder. The xenon transfer pressure is expected to be 3 – 7 psig.

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[1] The presentations, these Minutes and the referenced documents herein are posted at: http://www.rhichome.bnl.gov/AGS/Accel/SND/laboratory_environemnt,_safety_and_health_committee.htm.)

[2] Since each cryostat is a two walled vessel with an annular vacuum, 1 psi on the inner vessel causes a 15.7 psi differential pressure (psid).

1.1.10. The results of the inner vessel stress analyses, presented at the April 3, 2003 CSC meeting, were reviewed.
   1.1.10.1. Inner vessel differential pressures of 15.8 and 31.6 psid were assumed.
   1.1.10.2. The maximum stress and strains occur in the lower disk.
   1.1.10.3. In both cases, the stress was above yield for the lower disk. However, the strain values indicate it does not approach ultimate stress.
   1.1.10.4. No other area approached yield.
   1.1.10.5. The proposed maximum system operating pressure of 10 psi (24.7 psid) is enveloped by the 31.6 psid analysis.

1.1.11. A test model of the inner vessel was pressurized to 96 psig without failure.

1.1.12. The Committee noted that the device does not meet the requirements of the ASME Code. However:
   1.1.12.1. The device, if it were to fail, is contained within a second vessel.
   1.1.12.2. The relief valve capacity is more than adequate to safely vent the excess pressure if the inner vessel did fail.
   1.1.12.3. The discharges from all rupture disks and relief valves will be directed away from personnel that might be in the area.

1.2. The following motion was crafted by the Committee:

1.2.1. Motion No. 1 -The proposal to operate the PHENIX TEC/TRD Xenon Recovery System at a maximum pressure of 10 psig during xenon transfer operations is approved, subject to the following conditions:
   1.2.1.1. Replace the inner vessel relief valve (RV) with a new RV. The new RV shall be set at 10 psig and have the same flow capacity as the existing valve.
   1.2.1.2. Install a stack (or similar device) to direct effluent from all relief devices away from personnel.
   1.2.1.3. Prior to the next running period (July '04) perform an inner vessel redesign and replacement cost study[3, 4]. Present the results to this Committee.
   1.2.1.4. Pressurize the test model of the inner vessel to failure. (See also Section 1.1.11.) Report the data to the Committee, in concert with the redesign/replacement cost study of 1.2.1.3 – **Complete**[1, 5].

1.2.2. W. Glenn made a recommendation for approval of the Motions.

1.2.3. Seconded by M. Iarocci.

1.2.4. The motions were approved by vote of 5 in favor, none opposed with one abstention.

2. The Meeting was adjourned at 2:45 p.m.

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[3] Inner vessel redesign should meet the intent of the ASME code and rework the present non-conforming weld configuration.

[4] The Committee will provide cryogenic design acceptance criteria for the inner vessel redesign/replacement study.

[5] This action was completed prior to the issuance of these minutes. The test model failed to hold pressure at 1000 psi due to a small break in the weld on the top of the vessel.

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for the U. S. Department of Energy

Memo

Date: April 3, 2003

To: Distribution

From: Richard Thomas, Chairman, Cryogenic Safety Committee

Subject: Minutes of the CSC Meeting of 03 April 2003

Review of the Xenon Recovery System for the PHENIX TRD — Meeting 2

Members Present: Richard Thomas *(Chairman)*, M. Gaffney *(ex-officio)*, M. Iarocci, P. Kroon, P. Mortazavi, and K. C. Wu

Members Absent: S. Kane, M. Rehak

Others Attending: J. Muratore *(Recording Secretary)*, L. Kotchenda, A. Franz (PHENIX), R.Pisani (PHENIX), C. Biggs (PHENIX), S. Bellavia (C-AD), A. Etkin (C-AD), E. Lessard (C-AD), E. O'Brien (Physics)

The meeting was called to order by the chairman at 1:30 pm in Conference Room 63 of Building 902. Representatives of the PHENIX Detector Group, Achim Franz, P. Kroon (also a CSC member), Robert Pisani, and Carter Biggs were present.

Review of the Xenon Recovery System for the PHENIX TEC/TRD

The purpose of this meeting was to consider the eight items that were raised by the CSC at the initial review, on 24 January 2003, of the Xenon gas recovery system for the PHENIX Time Expansion Chamber (TEC) and its future upgrade, the Transition Radiation Detector (TRD). The eight recommendations of the committee after the first meeting were:

1) design stress calculations for any cryostat or device that will see a pressure differential in excess of 1 atm to verify that it complies with the ASME Boiler Code;
2) a correct and complete system drawing;
3) formal written operating procedures in a format that can be easily followed by the operators;
4) high pressure cryogenic valves for the small xenon vessel and liquid nitrogen storage dewars, or verification that these valves can not be simultaneously subjected to very low temperatures and very high pressures;
5) check or relief valve between the 6.9-liter vessel and the cryostat inner vessel to prevent backflow of 1400 psi Xe gas;
6) added lines and/or a heat exchanger to warm the xenon gas going into the 43.5-liter xenon vessel, or calculations showing that it is not needed;
7) more information on critical components, such as valves, from manufacturers;
8) a passive relief system for the cryostats that will vent in such a manner that any personnel in the vicinity will not be struck by the gas being vented. (A relief system that depends on personnel

taking a specific action, such as removal of bolts, was not felt to be in compliance with generally accepted practice.)

To answer Item 1, Peter Kroon showed the stress analysis for the inner pressure vessels of the cryostats used to liquefy the xenon gas. He noted that the inner vessel was too small to come under ASME code requirements. Stress calculations showed that wall thickness and allowable pressure differentials were much higher than needed for the operating conditions, with the exception of the bottom ellipsoidal disc, which will yield slightly on first use but not experience a catastrophic failure. Afterwards, for all further operations, the vessel will perform within specifications. It was concluded that the welded joint, which will see the highest stress, was satisfactory. The results of a finite element analysis by ANSYS were presented to establish these conclusions.

Item 8 was answered by the addition of a relief valve for each cryostat. A question on the sizing of the valves by M. Iarocci was answered by stating that they were sized for twice the maximum expected flow rate.

Items 4 and 6 were shown to be met by studying the new P&ID, which showed that cold valves were not needed now that heat exchangers had been added to the system to warm the gas. These valves no longer have the potential of being subjected to gas at very low temperatures.

Item 5 was satisfied by showing that relief valves did protect the cryostat from back flow of 1400 psi Xe gas from the 6.0-liter vessel.

For Item 3, a procedure, written by L. Kotchenda, was provided. The committee chose the section describing the extraction of xenon to review step-by-step while comparing the instructions in each step to the P&ID drawing. Questions did come up, such as more specific naming and/or labeling of certain pressurized vessels for reference in the procedures. It was also recommended that the procedure be submitted to the standard C-AD review process.

Item 7 was satisfied by the valve certifications, provided by the manufacturer and by other information provided by manufacturers of the various components. This additional information satisfied the recommendation of the committee regarding this item.

Lastly, Item 2 was considered to have been satisfied, since the P&ID had, during the review process, been checked thoroughly during the discussion of the other items.

Recommendations:

Approval was given contingent upon a satisfactory response to the following three recommendations:

1) that the written operating procedures be submitted for review and approval by C-AD,
2) that a name should be assigned to the 43.5-liter bottle in the procedure, and
3) that the C1 and C2 bottles be labeled as being pressurized bottles.

It was agreed that the three items above may be satisfied and approval given without the need for another committee meeting.

The meeting was adjourned at approximately 3:15 pm.

Approved: Richard Thomas

Richard Thomas, Chairman, CSC

rt/jm

Attachments

Distribution:

T. Sheridan
Members of the Cryogenic Safety Committee
A. Franz, R. Pisani, E. O'Brien
E. Lessard, R. Karol, W. Glenn

Superconducting Magnet Division

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Memo

Date: January 24, 2003

To: Distribution

From: Richard Thomas, Chairman, Cryogenic Safety Committee

Subject: Minutes of the CSC Meeting of 24 January 2003

Review of the Xenon Recovery System for the PHENIX TRD

Members Present: Richard Thomas *(Chairman)*, M. Gaffney *(ex-officio)*, M. Iarocci, S. Kane, P. Kroon, P. Mortazavi, M. Rehak, and K. C. Wu

Members Absent: None

Others Attending: J. Muratore *(Recording Secretary)*, C. Biggs (PHENIX), A. Etkin (CAD), A. Franz (PHENIX), R.Pisani (PHENIX)

The meeting was called to order by the chairman at 1:30 pm in Conference Room 63 of Building 902. Representatives of the PHENIX Detector Group, Carter Biggs, Achim Franz, and Robert Pisani were present.

The chairmen first introduced and welcomed a new member of the committee, Payman Mortazavi (NSLS), replacing M. Woodle, who has retired.

Review of the Xenon Recovery System for the PHENIX TEC/TRD

Achim Franz of PHENIX gave the presentation regarding a new Xenon gas recovery system for the PHENIX. The Time Expansion Chamber (TEC), which uses an operating gas mixture of 90% Ar + 10% CH_4, is being upgraded to a Transition Radiation Detector (TRD). The TRD requires a gas mixture that will convert X-rays into clusters of electrons. Two sets of printed handouts, distributed to the members at the meeting, accompanied the discussion. After describing the TEC and what it does, he explained the reason for replacing the argon in the present TEC gas mixture with helium and xenon. Photon absorption by xenon is four times greater than for argon. The proposed gas mixture consists of 45% Xe + 45% He + 10% CH_4. In the case of the TEC, when the operating gas was the argon mixture, the gas was vented after use. Xenon, however, is expensive, so a semi-closed system for recovering the xenon has been designed and was the subject of this review.

The recovery system consists of the following components:

1) Two cryostats, each of which has an outer vacuum vessel, an inner pressure vessel, and a two-stage liquid nitrogen heat exchanger system for cooling xenon gas to liquid or solid and thus extracting it from the gas mixture. These were made by L. Kotchenda and tested to 2 atm.
2) 200-L liquid-nitrogen supply dewars, made by Cryofab .
3) A small 6.9-L vessel for liquid Xe, which sits in a bath of liquid nitrogen

4) A large 43.5-L tank for holding Xe gas.
5) Transfer lines, valves, and flow controllers.

First, it was pointed out that the system is located on a concrete pad *outside* the PHENIX building, and it is open. (The system is not located in a closed structure; the area has a roof, but no walls). This eliminates the need for an ODH calculation, since this is not a space that is subject to having the atmospheric oxygen displaced by expanding cryogenic gases. It was also pointed out that this system is a copy of a similar system that has been used at FNAL for the past ten years. A schematic of the system and a simplified flow diagram were presented.

Extraction of the xenon from the gas mixture is accomplished by passing the gas through the 2-stage heat exchanger system. The cooling is produced by the liquid N_2 flowing in the opposing loop of a heat exchanger. Xenon liquefies at 165.1 K and solidifies at 161.4 K. Methane remains a gas for temperatures above 112 K. (Methane solidifies at about 90 K.) Temperature is controlled by adjusting the liquid N_2 flow rate through the heat exchangers. Only one cryostat is used at a time, but the other one is kept cold and on standby in case the primary one fails. The 220-L liquid nitrogen dewars will be supplied by Cryofab, Inc. Cryofab is also the supplier for both of the xenon vessels, the small 6.9 L vessel and the large 43.5 L vessel.

The following were the three failure modes considered by the PHENIX group: loss of vacuum in the cryostats, loss of other thermal insulating vacuums; loss of power; and leakage of liquid N_2 into the vacuum space. In response to any of these events, valves will open to vent gas to the outside. The xenon would be lost.

The committee then brought up the following question. What if the valve between the cryostat (32 psi) and the small6.9 L dewar (1400 psi) were to fail. This could cause backflow and higher-than-rated pressure into the inner pressure vessel. A check or relief valve was suggested.

It was also noted that, although the cryostat and transfer lines had been tested to two atmospheres, the cryostat inner vessel had to meet the ASME boiler code for pressure vessels. To meet this requirement, there are two methods: stress calculations or proof test. However, a proof test would sacrifice a cryostat, since it must be pressurized until the metal response is nonlinear according to attached strain gauges. So design stress calculations need to be provided for the inner pressure vessel. There was also some concern expressed regarding the absence of a relief valve for the cryostat vacuum vessel. The project had proposed that the relief be provided by removing the bolts that hold the top plate to the vessel. This is contrary to standard practice and is not a passive relief system. The committee suggested that the tops stay bolted down and relief valves be provided.

The question of a failure somewhere along the liquid nitrogen flow circuit, such as a burst transfer line, was brought up. It was pointed out that there were 10 psi relief valves present. The committee noted that the flow schematic of the system was incomplete. Members requested that a complete schematic be provided, showing all valves and reliefs, so that a thorough check for any trapped volumes could be made. Committee members also asked for formal, written operating procedures.

Other requests by the committee included high-pressure valves that will operate under cryogenic conditions for the liquid nitrogen storage dewars and the small 6.9-L vessel, if indeed there are situations in which these valves could be cold and see very high pressures.. The valve provided with the 6.9-L vessel is probably not meant for cryogenic service, and the liquid nitrogen valves are not expected to be for use at 2000 psi. The vessels themselves meet the specifications as listed by Cryofab, Inc. But more information is needed about components, such as valves, from the manufacturers of the tanks and dewars. Can the larger 43.5-L xenon vessel get too cold? If so, a heat exchanger is needed to warm the gas coming from the 6.9-L vessel. The actual design for such a heat exchanger can be determined by calculations of the gas temperature from knowledge of the amount of xenon and the maximum flow rate.

In summary, approval of the PHENIX Xenon Recovery System as described was not given, and the committee will meet again to re-consider approval contingent a satisfactory response to the following concerns:

1) design stress calculations for the cryostats to verify that they comply with the ASME Boiler Code;
2) a correct and complete system drawing;
3) formal written operating procedures;
4) high pressure cryogenic valves for the small xenon vessel and liquid N2 storage dewars, or verification that these valves can not be simultaneously subjected to cryogenic temperatures and very high pressures;
5) check or relief valve between the 6.9-L vessel and the cryostat inner vessel to prevent backflow of 1400 psi xenon gas;
6) added lines and/or a heat exchanger to warm the xenon gas going into the 43.5-L Xe vessel, or calculations showing it is not needed;
7) more information on components, such as valves, from manufacturers;
8) real relief valves for the vacuum spaces of the cryostats.

New Cryogenics SBMS Subject Area

Regarding other business, Mike Gaffney announced that a new cryogenic SBMS subject area is being produced. It will consider the handling and safety hazards of cryogens and include CSC guidelines. He asked for volunteers to review the documents being produced for this subject area. Steve Kane and Mike Iarocci volunteered. The chairman requested that he send a formal notice to all members of the committee inviting each member to participate in producing the material for the cryogenic safety subject area.

Recommendations:

No final recommendations were made at this time. The committee will meet again to re-consider approval contingent on a satisfactory response to the eight concerns listed above.

The meeting was adjourned at approximately 2:50 pm.

Approved: Richard Thomas

Richard Thomas, Chairman, CSC

rt/jm

Attachments

Distribution:

T. Sheridan
Members of the Cryogenic Safety Committee
A. Franz, R. Pisani
E. Lessard, R. Karol, W. Glenn

Xenon Recovery System for the PHENIX TRD

Version 8.3
27th June 2003

Performed by:
L.Kotchenda
07/25/02

Modified: A.Franz, BNL
Version 08 added stress calculation

Introduction

For the upgrade of the PHENIX Time-Expansion Chamber (TEC) to a Transition Radiation Detector (TRD) the operating gas has to be changed from the current 90%Ar + 10%CH_4 (P10) to a mixture that converts the created TR X-rays into electron clusters. Our choice is 45%He + 45%Xe + 10%CH_4.

The current system vents the gas after use, which would be too expensive with Xe, so from the beginning the TEC gas system was designed as a semi closed system.

Fig. 1 shows a schematic of the TEC/TRD gas system with the Xe recovery system placed on the current vent line (red box, upper right). The physical location of the recovery system is the PHENIX gas pad. All controls and alarm functions integrate into the existing TEC gas system.

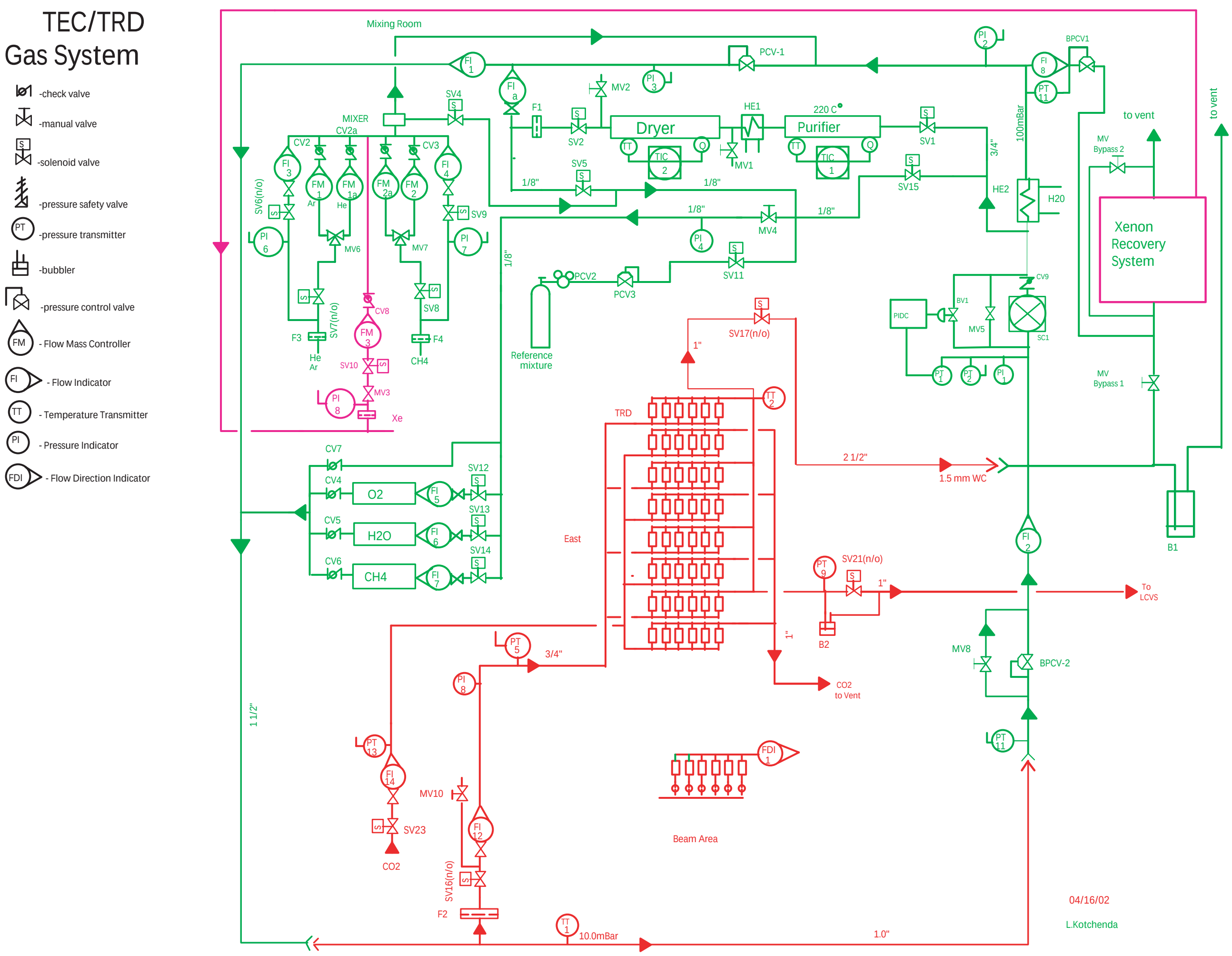


Fig. 1. PHENIX TEC/TRD Gas System

The recovery system extracts Xenon from the 45%He+45%Xe+10%CH_4 mixture venting from the chambers by use of a cold trap. The collected solid Xe is recovered, first to a transfer bottle in liquid form and then placed as a gas into commercial storage cylinders for re-introduction into the system.

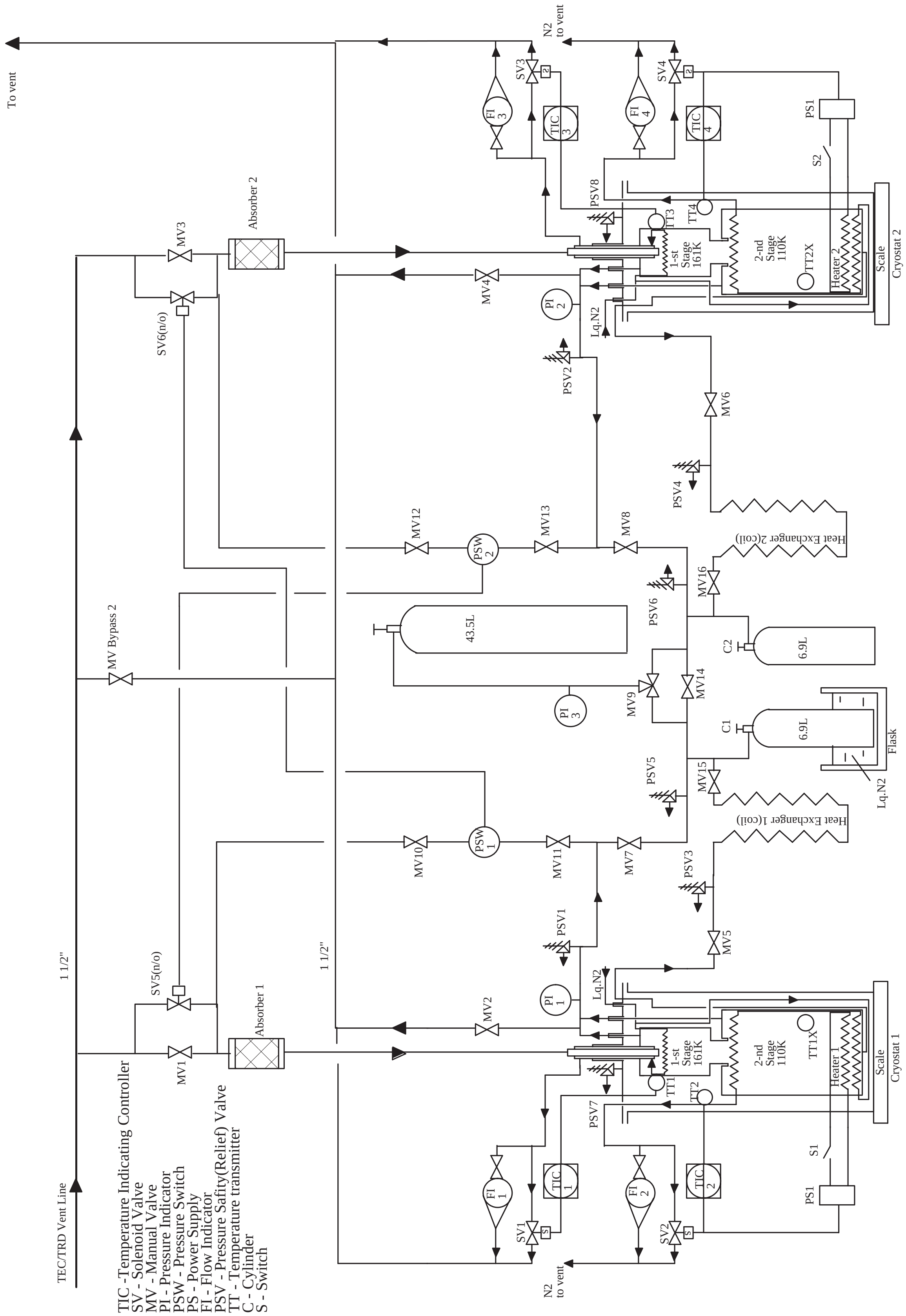


Fig.2. Xenon recovery system (TEC/TRD Gas System schematic 002-0206-911, Sheet 2)

The Xenon Recovery System

The Xenon recovery system itself is shown in Fig.2. It includes two low temperature cryostats, each capable of accumulating up to 6 liters of liquid Xenon. The cryostats have two stages of Xenon separation at different cryogenic temperatures, a first stage at 161K and a second stage at 110K where solid Xenon will be collected. For normal operation only one cryostat will be in the running mode, with the second one in standby. For TRD purging or power failures, both cryostats will be employed.

The coolant, liquid Nitrogen (N_2), flows through each of the two stage heat exchangers, controlled by a temperature-indicating controller (TIC). Two commercial 200 liters Dewars (CRYOFAB CFN-200-SS) with a custom transfer-line (Fig.2c) will be used to supply the cryostats with liquid N_2, see Fig.2b.

Each cryostat has an absorber on the mixture input line to remove CO_2 and H_2O remains.

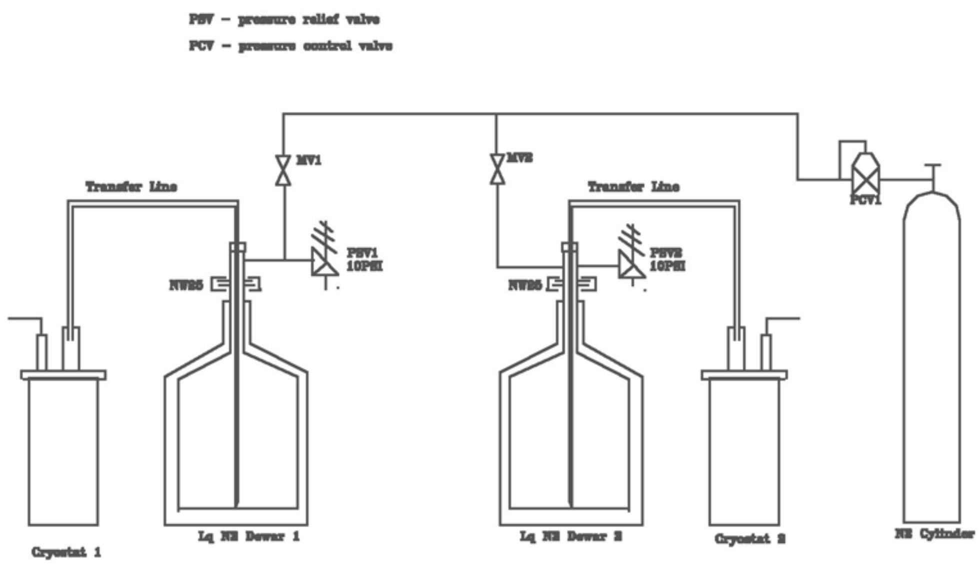


Fig.2b. Simplified view of the Nitrogen Supply flow on the Xenon recovery system

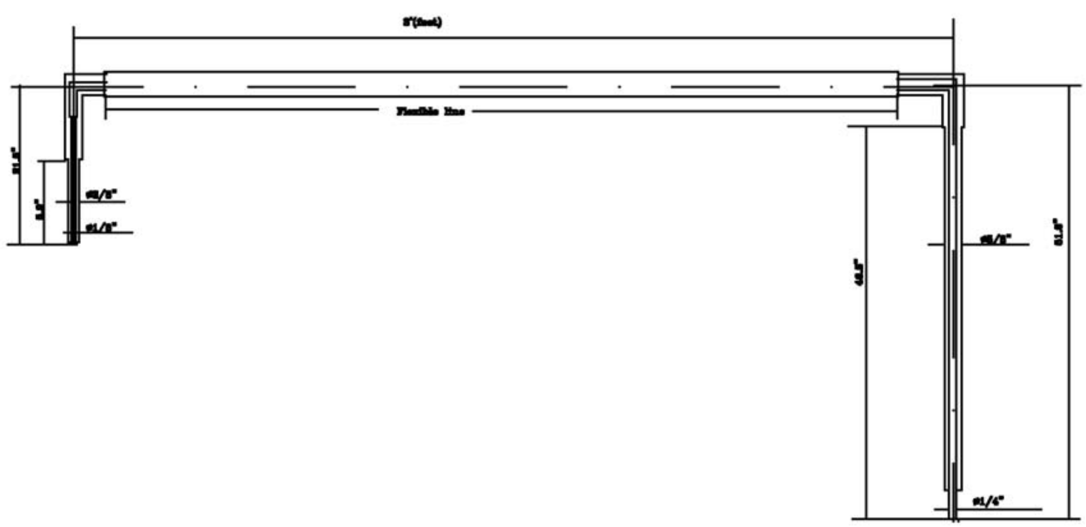


Fig.2c. Detail of the N_2 supply transferline

In case the input line of the operating cryostat is plugged up operation will be switched over to the second cryostat automatically by the pressure switch PSW1 or PSW2, set at 3mm WC.

A scale measures the amount of Xenon, recovered by the second cryostat stage.

1 PSI relief valves (PSV1, PSV2) on the second stage and the cryostats vent lines prevent accidental overpressure of the cryostats stages.

Each cryostats second stage has a RTD (100Ωm) temperature transmitter (TT1X, TT2X) connected to the TEC/TRD gas system readout electronics to monitor the cryostats internal temperature and pressure. The shift crew will be informed by an audible and optical alarm in the case the temperature and/or pressure exceeds a predefined set point (130K/3mmWC).

Xenon Recovery Cryostat Design Details

The cryostat design is shown in Fig.3. Its demountable vacuum jacket allows access to the inside parts. The cylindrical part of vacuum jacket (1)[1] is made from 1.2mm thick stainless steel with a diameter of 200mm. The vacuum jacket bottom plate (2) is 2 mm thick.

The first cryostat stage (3) is connected to the vacuum jacket flange (4) by the input (5) and output (6) mixture pipes and thermometer pipe (7). The top part of first stage contains a heat exchanger (8) using for Xenon condensation.

A heat exchanger (9) on the mixture input pipe (5) cools the mixture before it enters the first stage. Outgoing Nitrogen gas from the heat exchanger (8) is used as the coolant. The inner diameters are 14.5mm for the mixture input pipe and 7.5mm for the output pipe (6).

The second cryostat stage is connected to the first one by a 52.6mm inner diameter pipe and to the flange (4) by several pipes (liquid Xenon Out, Xenon Gas/Heater Out, two thermometers pipes).

The second stage vessel is made from 1mm stainless steel.

Inside are:

- two heat exchangers (11 top and 12 bottom, connected in series),
- a heater (13),
- copper temperature equalizer (14),
- thermometers (TT1X or TT2X).

For thermal insulation the second stage is covered with many layers of vacuum insulation (15).

During construction the assembly was pressurized to an absolute pressure of 2 atm for the inner part, with 0 atm in the vacuum jacket and 1 atm pressure outside.

For the initial startup a pump will establish a sufficient vacuum in the jacket.

[1] Numbers in brackets refer to the drawing in Figure 3.

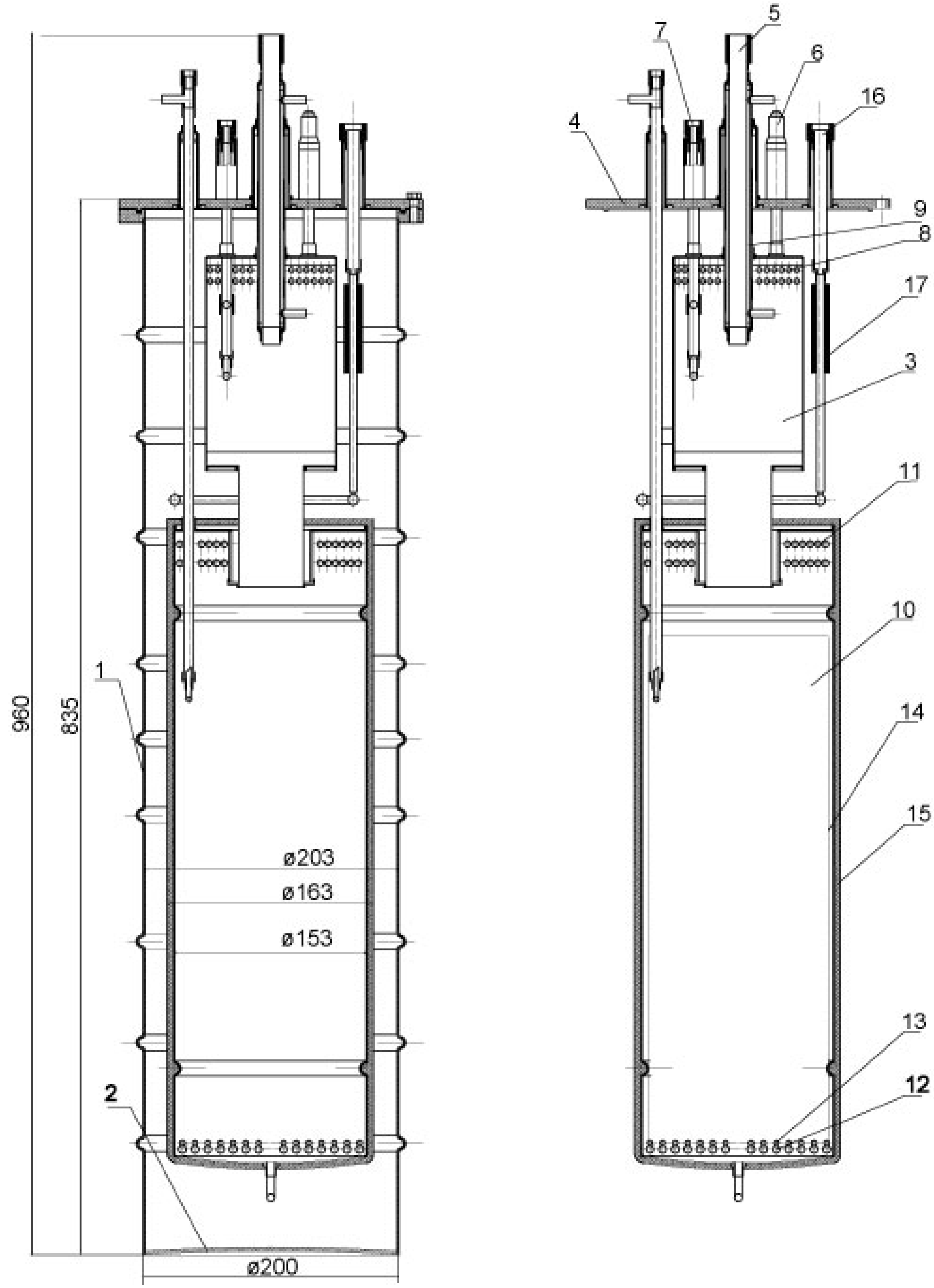
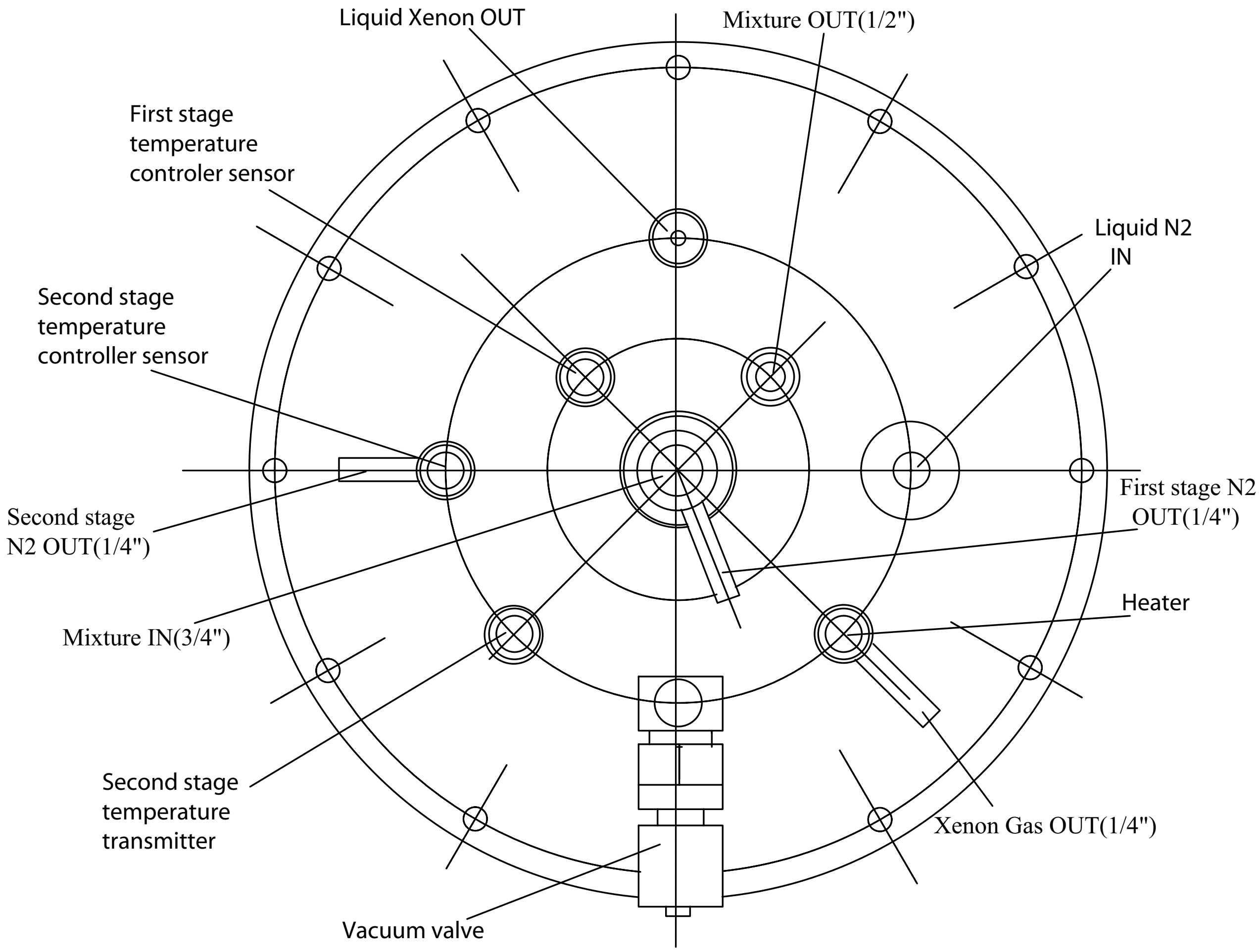


Fig.3. Xenon Recovery Cryostat (Xenon Gas Recovery Cryostat 002-0206-913)

All cryostat connections located on the flange (4) are shown in the Fig.4.



<u>Fig.4. Xenon Recovery Cryostat Connections</u>

Liquid Nitrogen is supplied through the connector 16 in Fig.3 to the first and second cryostat stages. The absorber, charcoal, (17) is used to support a stable vacuum level.

<u>Nitrogen flow</u>

Fig.5 shows a schematic of the N_2 flow through the cryostat heat exchangers.

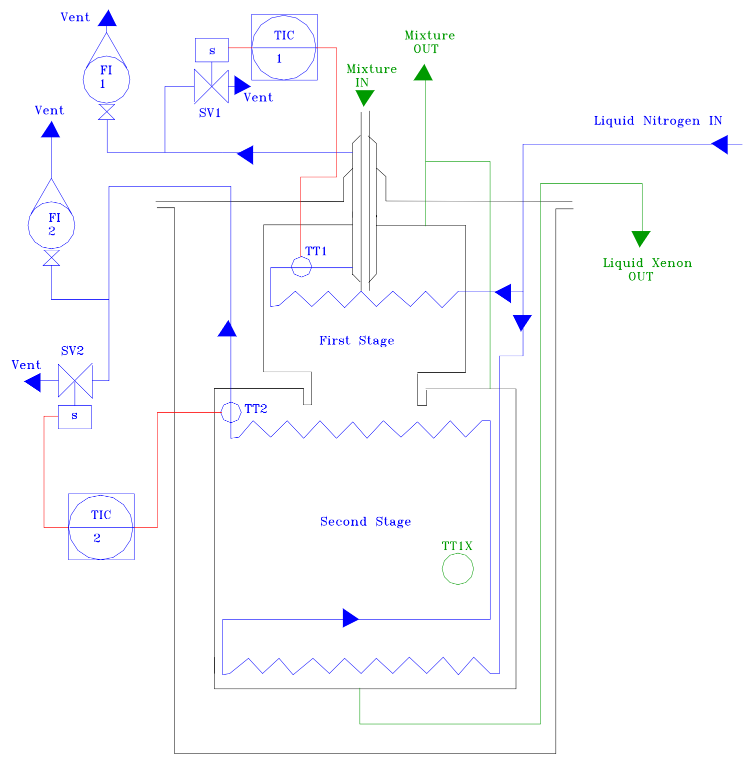


Fig.5. Nitrogen flows through the heat exchangers

Liquid N_2 from the storage vessels enters the two recovery stages with its flow controlled by a temperature-indicating controller (TIC) and monitored by thermometers TT1 and TT2. Part of the outgoing N_2 is used to pre-cool the incoming gas mixture and also to dilute the outgoing gas to non-flammable levels.

Xenon removal from the cryostat.

Xenon will be removed from the cryostats at 0.1PSIG (input and output closed).

The Xenon removal process from the cryostat to a commercial 6.9l stainless steel vessel will take 60-80 minutes under constant operator control. The operator will monitor the liquid N_2 level in the flask containing the 6.9l stainless steel vessel during the extraction process.

The second stage is heated to 164K to transform the solid Xenon into a liquid. A heater element reduces the heating time. Xenon is transferred into a 6.9 liters stainless steel vessel placed into liquid Nitrogen. After being disconnected from the cryogenic system the 6.9 liters vessel is heated up to room temperature and the Xenon gas is transferred into a 43.5 liters commercial storage cylinder for re-integration into the system. Appendix E shows the test result from of a pressure test of these commercial vessels.

Basic Xenon Cryostat parameters

Operating flow	0.5 liters/min
Purge flow	4 liters/min
First Stage Volume	1.3 liters
Second stage volume	8.6 liters
Operating pressure: Xenon collection Mode	0 atm (0 PSI)
Tested to, by L.Kotchenda	2 atm (30PSI, absolute)
Nitrogen consumption	~ 5 liters / 24hr
Cryostat weight	14.4kg (31.7lb).

System response to operating failures

Following is a list of possible failure modes and how the system is assigned to cope or recover from these failures:

- **Loss of vacuum**
  In this case the temperature values measured with TT1X and TT2X will exceed the set point of 130K and the TEC/TRD control system will inform the shift crew about this by an audible and optical alarm. Nothing will happen with the stages pressure because the cryostats outputs must be opened to the vent line for normal operation. If the output and input lines are accidentally closed the relief valves (PSV1, PSV2) will prevent overpressure.
- **LN_2 leak into vacuum space**
  To prevent overpressure inside the vacuum space the vessel is equipped with a burst disk which will vent the gas away from the operator.
- **Break of heat exchanger pipes**
  In case any of the two heat exchangers breaks and releases LN_2 into either stage 1 or 2, the nitrogen will boil off and vent into the open vent lines, which also have 1.0psi relieve valves.
- **Loss of power**
  In this case both cryostats inputs will be connected to the TRD vent line via SV5 (N/O) and SV6 (N/O) to collect Xenon. Nitrogen flow through FI1-FI4 will maintain the stage temperature close to set point controlled by the TICs at 160K for the first stage temperature and 110K for the second.

Relief valve on LN_2 lines.

These commercial lines can be operated at pressures up to 400PSIG, but being in line with valves SV1-SV4, set to a maximum operating pressure of 40PSIG, the effective pressure in the lines cannot exceed this value.

The commercial LN_2 dewars will be kept at 10PSIG pressure and have the relief valves. No liquid can be trapped inside the commercial transfer-lines as they do not have shut off valves.

Relief valves sizing

Appendix A contains a calculation of the pipe diameters and flow rates necessary for the relief valves PSV1 and PSV2. In case of bad vacuum the TICs will attempt to maintain the set point temperatures using more LN_2 compared to normal operation. If the second stage reaches a temperature of 130K the shift crew will be informed by the computer control.

Technical Specs of the Supply dewars

The N_2 supply dewars are commercial products by CRYOFAB (www.cryofab.com) who also manufacture the transfer-lines (Figs 2b and c).

Specs of the 200l N_2 supply dewars from the CRYOFAB web pages.

Net capacity (Liters)	25	50	100	200
Gross capacity (Liters)	28	55	110	220
Outer diameter (Inches/mm)	16/407	18/457	20/508	24/610
Height (Inches/mm)	28/711	33/838	41/1042	48/1220
Weight empty (lbs./Kg)	36/16.4	61/27.7	121/55	220/100
Weight full (lbs./Kg)				
LN2	81/36.8	150/68	299/136	577/262
LOX	99/45	187/85	373/170	724/329
LARG	111/51	211/96	421/191	820/373
Depth	22”	26”	35.5”	43”
M.A.W.P.	10 psig	10 psig	10 psig	10 psig
Static Loss/Day (CFN)	0.65/ltrs	0.70/ltrs	1.2/ltrs	1.2/ltrs
Neck Diameter (CFN)	0.75”o.d.	0.75”o.d.	1.0”o.d.	1.0”o.d.
Static Loss/Day (CFL)	0.87/ltrs	1.2/ltrs	1.3/ltrs	1.35/ltrs
Neck Diameter (CFL)	1.5”o.d.	1.5”o.d.	1.5”o.d.	1.5”o.d.

Specs of the open flask dewar from the CRYOFAB web pages

Model	CF8512”A” Inside Diameter (Inches)	“B” Outside Diameter (Inches)	“C” Inner Depth (Inches)	“D” Overall Height (Inches)	Gross Capacity (Liters)	Loss Rate (Liters/ Hr)	Liters/ Inch
CF9518	8.46	9.10	18.0	22.0	16.557	0.163	0.919

Technical Specs of the Valves

Valve #	Model	Manufacturer	Pressure Rating, PSIG	Temperature Range, F
MV1-MV4	B-45S8	Swagelok	2500	10 – 150
MV5-MV6	EC4-082-CWPR1M	Cryolab	400	-456 - +300
MV7-MV8, MV14-MV16	SS1RS4	Whitey	5000	-65 - +450
MV9	SS42XS4	Swagelok	2500	10 - 150
MV10, MV12	B4JNA	Swagelok	600	-40 - +150
MV11, MV13	B42S4	Swagelok	2500	10 - 150
SV1-SV4	E52K8DCCM	Peter-Paul	45	10 – 150
SV5-SV6	8210G34	ASCO	125	32 – 125

Appendixes:

A: Estimation of Relief Valve for the Xenon Recovery Cryostat

B: Results from the pressure test of the stainless steel flasks

C: Temperature Test of 6.9liter Stainless Steel Cylinder Valve

D: Xenon Cryostat Stress Calculations

E: Physical properties of liquid Xenon and Methane

F: Operating the PHENIX Xenon Recovery System

G: Memo: Xenon Gas Recovery Cryostat Lower Disk Analysis

Appendix A:

<u>Estimation of Relief Valve for the Xenon Recovery Cryostat</u>
<u>Performed by L. Kotchenda</u>

Consider the worst case when 45%He+45%Xe+10%CH4 mixture is in the vacuum volume at 1 ata (absolute), all valves are closed, second cryostat stage contains 6l liquid Xenon at 1.07ata (165.15K), no N_2 coolant flow through the heat exchangers.

Assume, that the heat transfer to the volume with liquid Xenon takes place by means of the mixture thermal conductivity and the thermal conductivity coefficient (k) is estimated at 300K, room temperature.

$k=0.45 \times k_{He} + 0.45 \times k_{Xe} + 0.1 \times k_{CH4}$,

with $k_{He} = 0.153$W/mK [1]

$k_{Xe} = 0.034$W/mK [1]

$k_{CH4} = 0.005$W/mK[1],

resulting in $k = 0.085$W/mK.

The thermal power is determined as

$Q = k \times (F/L) \times (T_1-T_2)$, where

F- second stage surface, m^2,

L- distance between the second stage wall and vacuum jacket the one, m,

T_1 – vacuum jacket wall temperature, K,

T_2 - second stage wall temperature, K.

The second stage has the following dimensions: outside diameter- 0.15m

height - 0.5m.

L = 0.025m.

T_1= 300K

T_2= 165.15K

Then $F = 0.785 \times (0.15^2) + 3.14 \times 0.15 \times 0.5 = 0.258m^2$

and

$Q = 0.085 \times (0.252/0.025) \times (300-165.15) = 158.5$W.

The mass amount of evaporated Xenon is

$m = Q/r$, where r - Xenon latent evaporation heat, J/g

r = 95.5J/g [1].

In this case

m = 158.5/95.5 = 1.66g/s .

Consider the case when the relief valve is connected directly to the first and second stages outputs, which are joined on the cryostat top. We have a rectangular connection to the relief valve.

The output dimensions are as follows:

First stage: inner diameter – 7.5mm

length - 115mm

Second stage: inner diameter – 7.5mm

length - 340mm

Consider the shortest first stage output.

Heat transfer to the first stage volume through the output SS pipe (8x0.25mm) is

$Q_1 = k \times F/L \times (T_1 + T_2)$, where

$F = 0.785 \times (0.008^2 – 0.0075^2) = 6.18 \times 10^{-6}\ m^2$ -pipe cross section,

K = 8.2W/mK in the temperature range of 165 –300K

Then $Q_1 = 8.2 \times 6.18 \times 10^{-6} \times (300 – 165.15) = 6.8 \times 10^{-3} W$

Suppose, that all amount of coming out Xenon gas is flowing through the first stage output pipe, then the gas temperature increasing can be estimated approximately as

$dT = Q_1/c_p \times m$, where c_p – Xenon thermal capacity at 165.15K

$c_P = 0.334 J/gK$ [1] and

$dT = 6.8 \times 10^{-3}/(0.334 \times 1.66) = 0.012K$

<u>It means the outcoming Xenon gas will have a low temperature of</u>

$T_{Xe} = 165.15 + 0.012 = 165.16K$

At this temperature and 1.07ata pressure Xenon specific volume is equal

v= 0.1l/g [1]

In this case the flow rate is

V = v x m = 0.1 x 1.66 = 0.166l/s = **10LPM**

The pressure drop along the first stage output line is estimated in the attached MathCAD file (Attachment 1).

In accord with the pressure drop calculations we have for the 7.5mm diameter and $Re_i = 2.071 \times 10^4$

$)p =)p_{2i} +)p_{4i} +)p_{mi}$ = 0.287 + 0.138 + 0.134 =**0.559mBar**

The second MathCAD file (Attachment 2) contains the pressure drop calculations at the assumption when the relief valve is installed at a distance of 1m from the cryostat output and the Xenon gas has room temperature. The pipe has a 9mm inside diameter and the flow is 20LPM. In this case the pressure drop is

$)p =()p_{2i} +)p_{4i})_{115} + ()p_{2i} +)p_{4i} +)p_{mi})_1 =$

0.287 + 0.138 + 2.478 + 0.985 +0.175 = 4.069mBar(0.06PSI)

Conclusion :

Relief Valve has to have 1 psig Spring and flow rate more than 20LPM.

It may be Swagelok SS-8C –1 installed at 1m distance from the cryostat output using 9mm **inside-diameter pipe.**

References: 1. http://webbook.nist.gov/chemistry/fluid/

Attachment 1, MathCAD file

Pressure Drop Δp **mBar**

Performed by Kotchenda L

Laminar flow $\mathbf{Re} < 2000$

Turbulent flow $\mathbf{Re} > 4000$

Flow Rate $\mathbf{V}$ $\frac{\mathbf{m}^3}{\mathbf{s}}$

Density ρ $\frac{\mathbf{kg}}{\mathbf{m}^3}$

Diameter $\mathbf{d}$ **m**

Length $\mathbf{l}$ **m**

Dynemic viscousity η $\mathbf{Pa \cdot s}$

Roughness Δ **m**

Radius $\mathbf{R}$ **m**

Angle α **degree**

INPUT Parameters

Gas or Mixture Xenon

$\mathbf{V} := 16.8 \cdot 10^{-5}$ $\rho := 9.8$ $\eta := 1.35 \cdot 10^{-5}$

$\mathbf{l} := 0.115$ $\mathbf{d} := 0.001$ $\mathbf{i} := 1 .. 10$

$\Delta := 0.001 \cdot 10^{-3}$ $\mathbf{R} := 0.01$ $\alpha := 90$

Colculations

1 $\mathbf{d_i} := \mathbf{i} \cdot \mathbf{d} + 0.0005$

2 **Cross section**

$$\mathbf{s_i} := 0.785 \cdot (\mathbf{d_i})^2$$

3 **Velocity**

$$\mathbf{v_i} := \frac{\mathbf{V}}{\mathbf{s_i}}$$

4 **Reynolds**

$$\mathbf{Re_i} := \mathbf{v_i} \cdot \rho \cdot \frac{\mathbf{d_i}}{\eta}$$

If $\mathbf{Re_i} < 2000$ **then**

5 $\lambda\mathbf{1_i} := \frac{64}{\mathbf{Re_i}}$

6 $\Delta\mathbf{p1_i} := 0.5 \cdot \rho \cdot \lambda\mathbf{1_i} \cdot \mathbf{v_i} \cdot \mathbf{v_i} \cdot \frac{\mathbf{l}}{\mathbf{d_i} \cdot 133.322} \cdot 1.3332$

If $\mathbf{Re}$ $4.E3 - 1.E5$ **then**

7 $$\lambda 2_i := \frac{0.3164}{\left(\mathbf{Re_i}\right)^{0.25}}$$

8 $$\Delta p2_i := 0.5\cdot\rho\cdot\lambda 2_i\cdot v_i\cdot v_i\cdot\frac{l}{d_i\cdot 133.322}\cdot 1.3332$$

If Re 1.E5 – 1.E8 **then**

9 $$\lambda 3_i := 0.032 + \frac{0.221}{\left(\mathbf{Re_i}\right)^{0.237}}$$

$$\Delta p3_i := 0.5\cdot\rho\cdot\lambda 3_i\cdot v_i\cdot v_i\cdot\frac{l}{d_i\cdot 133.322}\cdot 1.3332$$

For rough pipes

10 $$\Delta l_i := \frac{\Delta}{d_i}$$

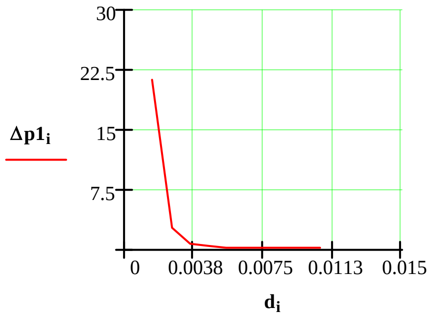
$$\lambda 4_i := \frac{1}{\left(1.74 + 2\cdot\log\left(\frac{1}{2\cdot\Delta l_i}\right)\right)^2}$$

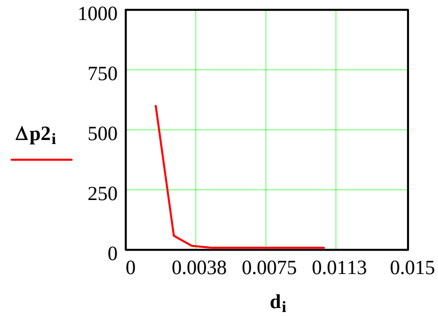
$$\Delta p4_i := 0.5\cdot\rho\cdot\lambda 4_i\cdot v_i\cdot v_i\cdot\frac{l}{d_i\cdot 133.322}\cdot 1.3332$$

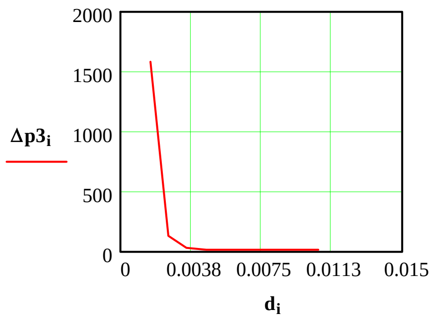
Local resistences
Bended pipes

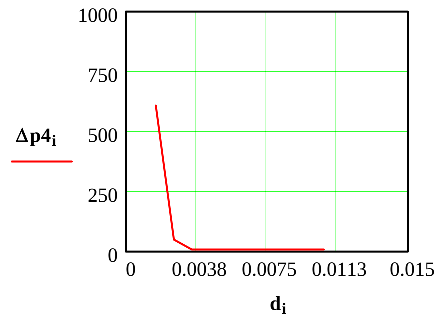
$$\zeta_i := \left[0.131 + 0.16\cdot\left(\frac{d_i}{R}\right)^{3.5}\right]\cdot\frac{\alpha}{90}$$

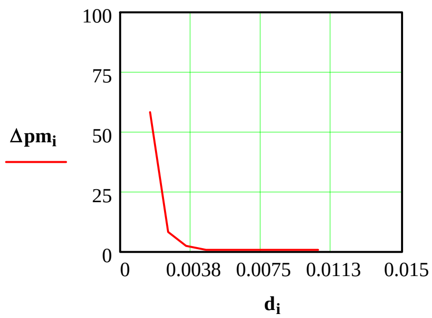
$$\Delta pm_i := \zeta_i\cdot\rho\cdot\frac{\left(v_i\right)^2}{2\cdot 133.322}\cdot 1.3332$$











d_i =	v_i =	Re_i =	$\Delta p1_i$ =	$\Delta p2_i$ =	$\Delta p3_i$ =	$\Delta p4_i$ =	Δpm_i =
$1.5 \cdot 10^{-3}$	95.117	$1.036 \cdot 10^{5}$	21.001	599.428	$1.574 \cdot 10^{3}$	605.805	58.166
$2.5 \cdot 10^{-3}$	34.242	$6.214 \cdot 10^{4}$	2.722	52.961	127.27	41.986	7.598
$3.5 \cdot 10^{-3}$	17.47	$4.439 \cdot 10^{4}$	0.709	10.711	24.323	7.262	2.02
$4.5 \cdot 10^{-3}$	10.569	$3.452 \cdot 10^{4}$	0.259	3.246	7.073	1.961	0.77
$5.5 \cdot 10^{-3}$	7.075	$2.825 \cdot 10^{4}$	0.116	1.252	2.64	0.69	0.37
$6.5 \cdot 10^{-3}$	5.065	$2.39 \cdot 10^{4}$	0.06	0.566	1.163	0.29	0.209
$7.5 \cdot 10^{-3}$	3.805	$2.071 \cdot 10^{4}$	0.034	0.287	0.576	0.138	0.134
$8.5 \cdot 10^{-3}$	2.962	$1.828 \cdot 10^{4}$	0.02	0.158	0.312	0.072	0.095
$9.5 \cdot 10^{-3}$	2.371	$1.635 \cdot 10^{4}$	0.013	0.093	0.181	0.04	0.073
0.011	1.941	$1.48 \cdot 10^{4}$	$8.747 \cdot 10^{-3}$	0.058	0.111	0.024	0.059

Kotchenda. L

Attachment 2, MathCAD file

Performed by Kotchenda L

Pressure Drop Δp **mBar**

Laminar flow $\mathbf{Re} < 2000$

Turbulent flow $\mathbf{Re} > 4000$

Flow Rate $\mathbf{V}$ $\frac{\mathbf{m}^3}{\mathbf{s}}$

Density ρ $\frac{\mathbf{kg}}{\mathbf{m}^3}$

Diameter $\mathbf{d}$ **m**

Length $\mathbf{l}$ **m**

Dynemic viscousity η **Pa·s**

Roughness Δ **m**

Radius $\mathbf{R}$ **m**

Angle α **degree**

INPUT Parameters

Gas or Mixture Xenon

$\mathbf{V} := 32 \cdot 10^{-5}$ $\rho := 5.73$ $\eta := 2.31 \cdot 10^{-5}$

$\mathbf{l} := 1$ $\mathbf{d} := 0.001$ $\mathbf{i} := 1 .. 10$

$\Delta := 0.001 \cdot 10^{-3}$ $\mathbf{R} := 0.01$ $\alpha := 90$

Colculations

1 $\mathbf{d_i} := \mathbf{i} \cdot \mathbf{d} + 0.000$

2 **Cross section**

$$\mathbf{s_i} := 0.785 \cdot (\mathbf{d_i})^2$$

3 **Velocity**

$$\mathbf{v_i} := \frac{\mathbf{V}}{\mathbf{s_i}}$$

4 **Reynolds**

$$\mathbf{Re_i} := \mathbf{v_i} \cdot \rho \cdot \frac{\mathbf{d_i}}{\eta}$$

If $\mathbf{Re_i} < 2000$ **then**

5 $\lambda\mathbf{1_i} := \frac{64}{\mathbf{Re_i}}$

6 $\Delta\mathbf{p1_i} := 0.5 \cdot \rho \cdot \lambda\mathbf{1_i} \cdot \mathbf{v_i} \cdot \mathbf{v_i} \cdot \frac{\mathbf{l}}{\mathbf{d_i} \cdot 133.322} \cdot 1.3332$

If $\mathbf{Re}$ $4.E3 - 1.E5$ **then**

7 $\lambda 2_i := \frac{0.3164}{(Re_i)^{0.25}}$

8 $\Delta p2_i := 0.5 \cdot \rho \cdot \lambda 2_i \cdot v_i \cdot v_i \cdot \frac{l}{d_i \cdot 133.322} \cdot 1.3332$

If Re 1.E5 – 1.E8 **then**

9 $\lambda 3_i := 0.032 + \frac{0.221}{(Re_i)^{0.237}}$

$\Delta p3_i := 0.5 \cdot \rho \cdot \lambda 3_i \cdot v_i \cdot v_i \cdot \frac{l}{d_i \cdot 133.322} \cdot 1.3332$

For rough pipes

10 $\Delta l_i := \frac{\Delta}{d_i}$

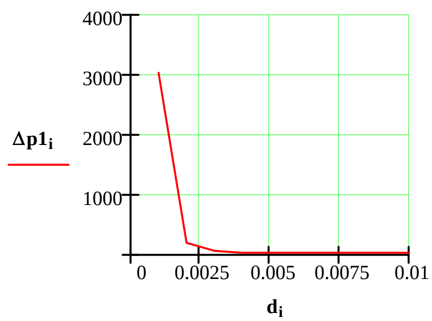
$$\lambda 4_i := \frac{1}{\left(1.74 + 2 \cdot \log\left(\frac{1}{2 \cdot \Delta l_i}\right)\right)^2}$$

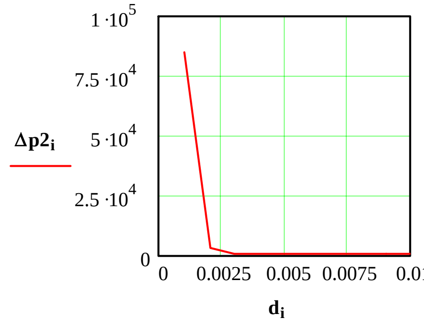
$$\Delta p4_i := 0.5 \cdot \rho \cdot \lambda 4_i \cdot v_i \cdot v_i \cdot \frac{l}{d_i \cdot 133.322} \cdot 1.3332$$

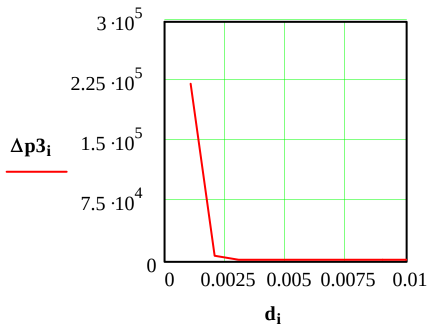
Local resistences
Bended pipes

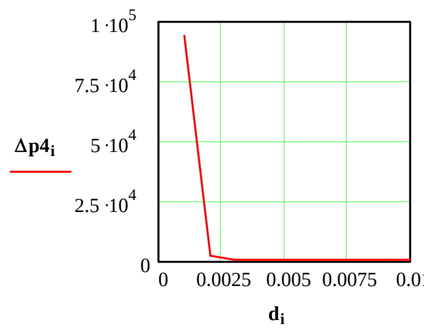
$$\zeta_i := \left[0.131 + 0.16 \cdot \left(\frac{d_i}{R}\right)^{3.5}\right] \cdot \frac{\alpha}{90}$$

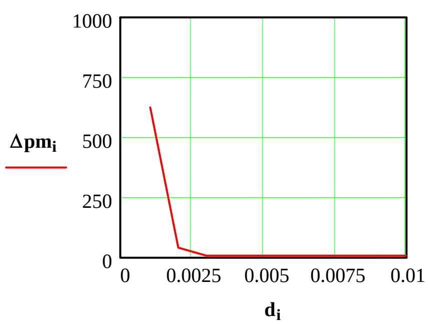
$$\Delta pm_i := \zeta_i \cdot \rho \cdot \frac{(v_i)^2}{2 \cdot 133.322} \cdot 1.3332$$











$d_i =$	$v_i =$	$Re_i =$	$\Delta p1_i =$	$\Delta p2_i =$	$\Delta p3_i =$	$\Delta p4_i =$	$\Delta pm_i =$
$1\cdot10^{-3}$	407.643	$1.011\cdot10^{5}$	$3.013\cdot10^{3}$	$8.447\cdot10^{4}$	$2.209\cdot10^{5}$	$9.344\cdot10^{4}$	623.904
$2\cdot10^{-3}$	101.911	$5.056\cdot10^{4}$	188.328	$3.139\cdot10^{3}$	$7.285\cdot10^{3}$	$2.483\cdot10^{3}$	39.149
$3\cdot10^{-3}$	45.294	$3.371\cdot10^{4}$	37.201	457.492	992.866	299.186	7.839
$4\cdot10^{-3}$	25.478	$2.528\cdot10^{4}$	11.771	116.661	241.739	66.809	2.557
$5\cdot10^{-3}$	16.306	$2.022\cdot10^{4}$	4.821	40.421	80.867	20.909	1.106
$6\cdot10^{-3}$	11.323	$1.685\cdot10^{4}$	2.325	17.002	33.069	8.1	0.58
$7\cdot10^{-3}$	8.319	$1.445\cdot10^{4}$	1.255	8.175	15.532	3.635	0.351
$8\cdot10^{-3}$	6.369	$1.264\cdot10^{4}$	0.736	4.335	8.073	1.816	0.237
$9\cdot10^{-3}$	5.033	$1.124\cdot10^{4}$	0.459	2.478	4.534	0.985	0.175
0.01	4.076	$1.011\cdot10^{4}$	0.301	1.502	2.706	0.57	0.139

Kotchenda. L

Appendix B:

Results from the pressure test of the stainless steel flasks

An independent company tested the stainless steel flasks, used for extracting the liquid Xenon from the cryostat and converting it back into gas. Attached is a copy of the fax documenting the test.

KAPLAN INDUSTRIES INC.
COMPRESSED GAS CYLINDERS

ROUTE 73 & MORRIS AVENUE
MAPLE SHADE, NJ 08052
PHONE: (800)257-8299 FAX: (856)779-8242
E-MAIL: kaplan@kaplanindustries.com
WEBSITE: www.kaplanindustries.com

DATE: 11/25/02

\# OF PAGES: 2

TO: Carter Biggs

COMPANY: National Labs

PHONE: 631-344-7575

FAX: 631-344-4592

FROM: Jim Johnston

FREDLOV Inc. Ultra Test-10

Kaplan Industries
Rte 73 & Morris Ave.
Mapleshade, N.J. 08052

High Pressure Cylinder Retest Report

Registration #: A622

Disposition Codes
PA - Passed Hydro & Visual
FH - Failed Hydro

I hereby certify that the following tests were made under my supervision & in accordance with applicable regulations.

Operator Signature: ______ Date: 10/23/02 Supervisor Signature : ______ Date : 10/24

#	Cylinder Serial #	Size	Customer	Last Gas Serv	Mfgr.	Mfgr. Date	Specification/ Rating	Pressure Test	Pressure Act.	Test: Time:	Volumetric Expansion (cc) Total:	Perm:%	Perm:	Elas:	REE	:+:*:Visual	:Disp:or	:Note :Remark
4	13853	6X28	WELCO	INER	WK	12-67	3AA2000	3165	3215	30	25.7	1.0	3.9	24.7	9999	PASS	PA	
5	26237	6X28	WELCO	INER	WK	12-67	3AA2000	3165	3265	30	28.6	2.8	9.8	25.7	9999	PASS	PA	

Appendix C:

<u>Temperature Test of 6.9liter Stainless Steel Cylinder Valve</u>

Performed by Leonid Kotchenda and Carter Biggs
03/10/03

- The lower half of the 6.9L SS Cylinder was placed in the liquid Nitrogen.
- Thermal couple (Iron – Constantan) was fixed in the point of Valve –Cylinder connection.
- The measurements were taken after the lower half of the cylinder was cool down to liquid Nitrogen temperature.

The test results are summarized in Table 1.

Time	2:26pm	2:36pm	2:46pm	2:56pm	3:06pm	3:16pm	3:31pm	3:37pm
Tc	+2^{o}C	+0^{o}C	+2^{o}C	+2^{o}C	+3^{o}C	+3^{o}C	+1^{o}C	+2^{o}C
To	+2^{o}C	+1^{o}C	+2^{o}C	+2^{o}C	+3^{o}C	+3^{o}C	+2^{o}C	+2^{o}C

Tc – Cylinder Valve Temperature
To – Outside Temperature

Appendix D:

Xenon Cryostat Stress Calculations

The cryostat inner vessels are too small (less than 6-inch inner diameter) to fit into the scope of the ASME Boiler & Pressure Vessel Code per U-1(c)(9). However, Code rules were used to calculate allowable working pressures where applicable.

The two formed heads facing each other at the bottom of the first stage and at the top of the second stage use weld joints not normally used in Coded vessels. However the highest stresses are bending stresses, which would be "secondary" stresses relievable by very minor yielding. This conclusion is supported by the FEA presented in Appendix G

Performed by Leonid Kotchenda
02/25/03

These calculations were performed in accordance with
1992 ASME Boiler & Pressure Vessel Code
Section VIII – Division 1.

1. Second stage cylindrical shell

   Determine the maximum allowable working pressure P of Xenon Cryostat second stage cylindrical shell for the following conditions:

   inner radius, R = 2.971in; outer radius, R_o = 3.01in; wall thickness, t = 0.039in;
   maximum operating temperature = 100^{o}F;
   minimum operating temperature = -255^{o}F;
   lowest efficiency of any joint in the head, E = 1.0;
   Vessel material – Stainless Steel Type 304.

From the appropriate table ULT-23, maximum allowable working stress, S = 18,800PSI at 100^{o}F; S = 20300PSI at –250^{o}F.
Consider the worst case, when the temperature is 100^{o}F:

$P = S \times E \times t/(R_o - 0.4 \times t) = 18800 \times 1.0 \times 0.039/(3.01 - 0.4 \times 0.039) = 244.9$PSI

a) Longitudinal Joint

$P = S \times E \times ((Z - 1)/(Z + 1))$, where

$Z = (R_o/R)^2 = (3.01/2.971)^2 = 1.03$,

$P = 18800 \times 1.0 \times ((1.03 - 1)/(1.03 + 1)) = 277.8$PSI

b) Circumferential Joints

$P = S \times E \times (Z - 1) = 18800 \times 1.0 \times (1.03 - 1) = 564PSI.$

2. Second stage Ellipsoidal bottom

Determine the maximum allowable working pressure P of Xenon Cryostat second stage Ellipsoidal bottom for the following conditions

outer diameter, D_o= 5.979in; inner diameter, D = 5.94in;
inside depth of ellipsoidal head, h = 0.39in; t = 0.039in.

$P = 2 \times S \times E \times t /((K \times D_o - 2 \times t \times (K - 0.1))$, where

$K = 1/6 \times ((2 + (D/2h)^2) = 1/6 \times (((2 + (5.94/(2 \times 0.39))^2) = 10$

$P = 2 \times 18800 \times 1.0 \times 0.039/((10 \times 5.979 - 2 \times 0.039 \times (10 - 0.1)) = 24.8PSI$

3. First Stage cylindrical shell

Determine the maximum allowable working pressure P of Xenon cryostat first stage cylindrical shell for the following conditions:

R=1.991in; R_o = 2.03in; t = 0.039in; E = 1.0

minimum operating temperature = - 190°F; S = 20,000PSI
maximum operating temperature = 100°F; S = 18,800PSI

$P = S \times E \times t/(R_o - 0.4 \times t) = 18800 \times 1.0 \times 0.039/(2.03 - 0.4 \times 0.039) = 364.8PSI$

a) Circumferential Joints

$Z = (R_o/R)^2 = (2.03/1.99)^2 = 1.04,$

$P = S \times E \times (Z - 1) = 18800 \times 1.0 \times (1.04 - 1) = 752PSI.$

Margin of Safety

Maximum working pressure of Xenon cryostat for both stages is **15.8 PSI,**
the ratio of allowable pressure/working pressure:

First stage

cylindrical shell	**364.8/15.8 = 23.1**
circumferential joints	**752/15.8 = 47.6**

Second stage

cylindrical shell	**244.9/15.8 = 15.5**
longitudinal joint	**277.8/15.8 = 17.6**
circumferential joints	**564/15.8 = 35.7**

ellipsoidal bottom **24.8/15.8 = 1.6**

Appendix E:

Physical properties of liquid Xenon and Methane

Xenon

T, K	161.36	162.36	163.36	164.36	165.36		
P, atm	0.81	0.86	0.91	0.96	1.02		
Δ_{gas}, kg/m^3	8.21	8.67	9.16	9.66	10.18		

Critical temperature – 289.7K; Critical density - 1100kg/m^3; Critical pressure - 58.4atm;
Normal boiling point (NBP)-165.05K ; Liquid Density at NBP –2940kg/m^3;

Methane

T, K	100.7	102.7	104.7	106.7	108.7	110.7	112.7
P, atm	0.37	0.45	0.55	0.66	0.79	0.93	1.1
Δ_{gas}, kg/m^3	0.72	0.87	1.03	1.22	1.44	1.69	1.96

Critical temperature - 190.56K   Critical density - 162.66kg/m^3
Critical pressure - 45.99atm   Normal boiling point – 111.67K

Appendix F:

Operating the PHENIX Xenon Recovery System

1.0 Purpose and Scope

The scope of this procedure is those operations that are necessary for running the East Transition Radiation Detector (TRD) with a mixture of 45%He + 45%Xe + 10% CH_4 using the TEC /TRD gas system together with Xenon Recovery system.
Operations in this procedure include the following:

1. Purging the Xenon Recovery System (XRS) with inert gases.
2. Purging the XRS with the mixture of 45%He + 45%Xe + 10% CH_4
3. Normal Operation Mode
4. Xenon removal from the cryostats

In the operation described here, inert gases (Nitrogen and Helium) and the mixture are routed from the TRD. The gas flow in the TRD Vent Line is typically 0.5 - 5 LPM at a pressure of 2 mmWC. Critical pressures and flows of the gas system are monitored by a hardware alarm box as well as a dedicated computer program.

The primary purpose of this operation is to recover Xenon from the mixture for the duration of the PHENIX operations. PHENIX Drawing # 002-0206-911B (Sheet 2), see Fig. 2, contains the definition of recovery system controls and instrumentation.

2.0 Prerequisites

2.1 Required training to operate the Xenon Recovery System in the manner described in 1.0 above:

2.1.1 BNL General Employee Training (GET)(V-001)
2.1.2 BNL Compressed gas safety course (OSH026)
2.1.3 BNL Cryogen Safety course (OSH025)
2.1.4 TEC/TRD gas system and Xenon Recovery System training with a previously qualified gas system operator.

3.0 Precautions

3.1 Overpressurization of the TRD (above 7 mmWC) will result in severe structural damage. Primary care should be given to monitoring the internal pressure of the East TRD throughout the duration of this procedure, especially when adjusting flow rates and when the hardware and software alarms are bypassed.

3.2 PPE: according to the cryogenics safety regulations the operator should wear gloves, an apron and safety goggles/face shield.

4.0 Procedure

4.1 Initial Setup

NOTE: The following procedure assumes that the East TRD has been flushed with nitrogen and that auxiliary systems have been turned on. TRD Leak rate does not exceed 0.2LPM. Xenon Recovery System pipes were purged with the inert gas and cleaned with Xenon. Both Xenon Cryostats insulating volumes were pumped to 10^{-3} Torr. 6.9L Cylinders (C1, C2) were pumped to 10^{-2}Torr.

4.1.1 Confirm that MV Bypass 2 is open and MV Bypass 1 is closed.
4.1.2 Confirm that there is the flow through FI8.
4.1.3 Confirm that MV5, MV7 and MV6, MV8 are closed.
4.1.4 Confirm that MV14, MV15 and MV16 are closed.

4.2 Purging the Xenon Recovery System with inert gases

4.2.1 Open MV1, MV2, MV3, MV4.
4.2.2 Open MV10, MV11, MV12, MV13.
4.2.3 Close MV Bypass 2.
4.2.4 Purge the cryostats at least 1 hour with a flow 5LPM.

NOTE: Once an acceptable leak rate has been established, go to East TRD purging with 45%He + 45%Xe + 10% CH_4

4.3 Purging the TRD with the mixture of 45%He + 45%Xe + 10% CH_4

4.3.1 Turn ON AC power to Xenon Cryostats Rack
4.3.2 Set TIC 1 and TIC 3 temperature to -112^0C(161K).
4.3.3 Set TIC 2 and TIC 4 temperature to -163^0C(110.2K).
4.3.4 Built up Dewars pressure to 8PSIG using cylinder's PCV.
4.3.5 Set FI1 and FI3 flow to 1LPM.
4.3.6 Set FI2 and FI4 flow to 2LPM.
4.3.7 Set Scales readings to 0(Zero).
4.3.8 Unblock Alarm TT1X and TT2X on TEC/TRD PC below 130K.
4.3.9 Purge 3 TRD's Volume

4.4 Xenon removal from the cryostats

4.4.1 Close MV3.

4.4.2 Check Scale of Cryostat 1.
4.4.3 Open MV3 at Cryostat 1 Scale reading 30lb .
4.4.4 Close MV1.

4.5 Xenon removal from the cryostats

Liquid Xenon from Cryostat 1

4.5.1 Block Alarm TT1X on TEC/TRD PC
4.5.2 Set TIC 1 and TIC2 to -108^{0}C(165.2K)
4.5.3 Turn On S1 for the heater 1 and let the temperature stabilized
4.5.4 Close MV10 and MV11
4.5.5 Place C2 to the flask.
4.5.6 Fill flask with lq.N_2 and cool down C2.
4.5.7 Close MV2
4.5.8 Open MV5 and MV15
4.5.9 Open C2 valve
4.5.10 Slowly open MV14 and let Xenon gas go to C2.
4.5.11 Check Cryostat 1 Scale and keep C2 cool.
4.5.12 Close C2 Valve at 15lb Scale reading.
4.5.13 Close MV14.
4.5.14 Close MV15.
4.5.15 Remove C2 from the flask and let C2 warm up.
4.5.16 Tern on MV9 to C2 direction.
4.5.17 Open 43.5L cylinder and check its pressure.
4.5.18 Close 43.5 Cylinder.
4.5.19 Open C2 Valve
4.5.20 Open 43.5L cylinder if the C2 pressure equals its pressure.

NOTE: **If the ambient temperature is below Xenon critical point (289K), use a blanket with the electrical heater to increase C2 or C1 temperature up to 310K (98F) to remove as much Xenon gas as possible.**

4.5.21 Close C2 valve and 43.5l cylinder valve at stable PI3 pressure
4.5.22 Place C1 to the flask and cool down it
4.5.23 Open C1 valve.
4.5.24 Slowly open MV15 and let Xenon gas go to C1.
4.5.25 Close MV5 valve at 0(Zero) Scale reading.
4.5.26 Close MV15.
4.5.27 Close C1 Valve
4.5.28 Turn on MV9 to C1 direction.
4.5.29 Remove C1 from the flask and let C1 warm up.
4.5.30 Open 43.5L cylinder and check its pressure.
4.5.31 Close 43.5L cylinder
4.5.32 Open C1 Valve.
4.5.33 Open 43.5L cylinder if C1 pressure equals its pressure.
4.5.34 Close C2 valve and 43.5L cylinder valve at stable PI3 pressure.
4.5.35 Open MV1 and MV2.
4.5.36 Turn OFF S1

4.5.37 Set TIC 1 and TIC 3 temperature to -112^{0}C(161K).
4.5.38 Set TIC 2 and TIC 4 temperature to -163^{0}C(110.2K).
4.5.39 Close MV1 when the TIC1 and TIC2 temperature will be stabilized.
4.5.40 Open MV10 and MV11.
4.5.41 Unblock Alarm TT1X on TEC/TRD PC
4.5.42 Check Cryostat 2 Scale readings.
4.5.43 Open MV1 if Cryostat 2 Scale reading is 30lb.
4.5.44 Close MV 3.

<u>Liquid Xenon from Cryostat 2</u>

4.5.45 Block Alarm TT2X on TEC/TRD PC
4.5.46 Set TIC 3 and TIC4 to -108^{0}C(165.2K)
4.5.47 Turn on S2 for the heater 2 and let the temperature stabilized
4.5.48 Close MV12 and MV13
4.5.49 Place C1 to the flask.
4.5.50 Fill flask with lq.N_2 and cool down C1.
4.5.51 Close MV4
4.5.52 Open MV6 and MV16
4.5.53 Open C1 valve
4.5.54 Slowly open MV14 and let Xenon gas go to C1.
4.5.55 Check Cryostat 1 Scale and keep C1 cool.
4.5.56 Close C1 Valve at 15lb Cryostat 2 Scale reading.
4.5.57 Close MV14.
4.5.58 Close MV16.
4.5.59 Remove C1 from the flask and let C1 warm up.
4.5.60 Tern on MV9 to C1 direction.
4.5.61 Open 43.5L cylinder and check its pressure.
4.5.62 Close 43.5 Cylinder.
4.5.63 Open C1 Valve
4.5.64 Open 43.5L cylinder if the C1 pressure equals its pressure.

NOTE: **If the ambient temperature is below Xenon critical point (289K), use a blanket with the electrical heater to increase C2 or C1 temperature up to 310K (98F) to remove as much Xenon gas as possible.**

4.5.65 Close C1 valve and 43.5l cylinder valve at stable PI3 pressure
4.5.66 Place C2 to the flask and cool down it
4.5.67 Open C2 valve.
4.5.68 Slowly open MV16 and let Xenon gas go to C2.
4.5.69 Close MV6 valve at 0(Zero) Cryostat 2 Scale reading.
4.5.70 Close MV16.
4.5.71 Close C2 Valve
4.5.72 Turn on MV9 to C2 direction.
4.5.73 Remove C2 from the flask and let C2 warm up.
4.5.74 Open 43.5L cylinder and check its pressure.
4.5.75 Close 43.5L cylinder
4.5.76 Open C2 Valve.
4.5.77 Open 43.5L cylinder if C2 pressure equals its pressure.

4.5.78 Close C2 valve and 43.5L cylinder valve at stable PI3 pressure.
4.5.79 Open MV3 and MV4.
4.5.80 Turn OFF S2
4.5.81 Set TIC 3 temperature to -112^0C(161K).
4.5.82 Set TIC 4 temperature to -163^0C(110.2K).
4.5.83 Close MV1 when the TIC3 and TIC4 temperature will be stabilized.
4.5.84 Open MV12 and MV13.
4.5.85 Unblock Alarm TT2X on TEC/TRD PC.

Appendix G:

Memo: Xenon Gas Recovery Cryostat Lower Disk Analysis MEMO:

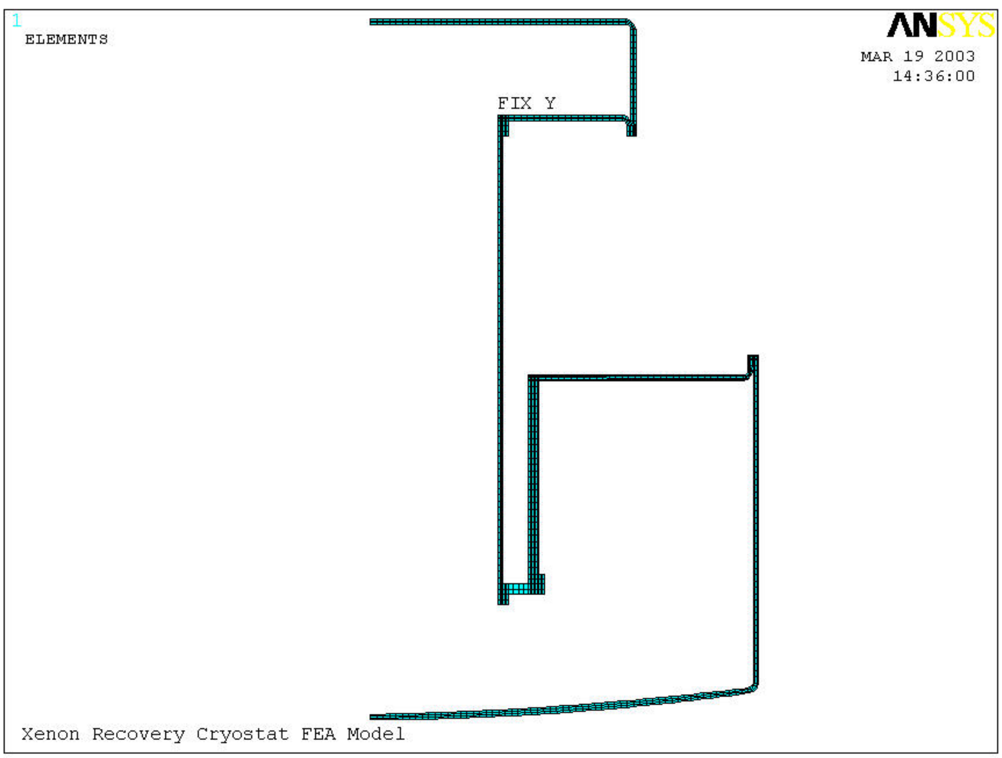
date: April 2nd, 2003
to: P.Kroon
from: S. Bellavia
cc: J. Tuozzolo
subject: Xenon Gas Recovery Cryostat Lower Disk Analysis - revised results

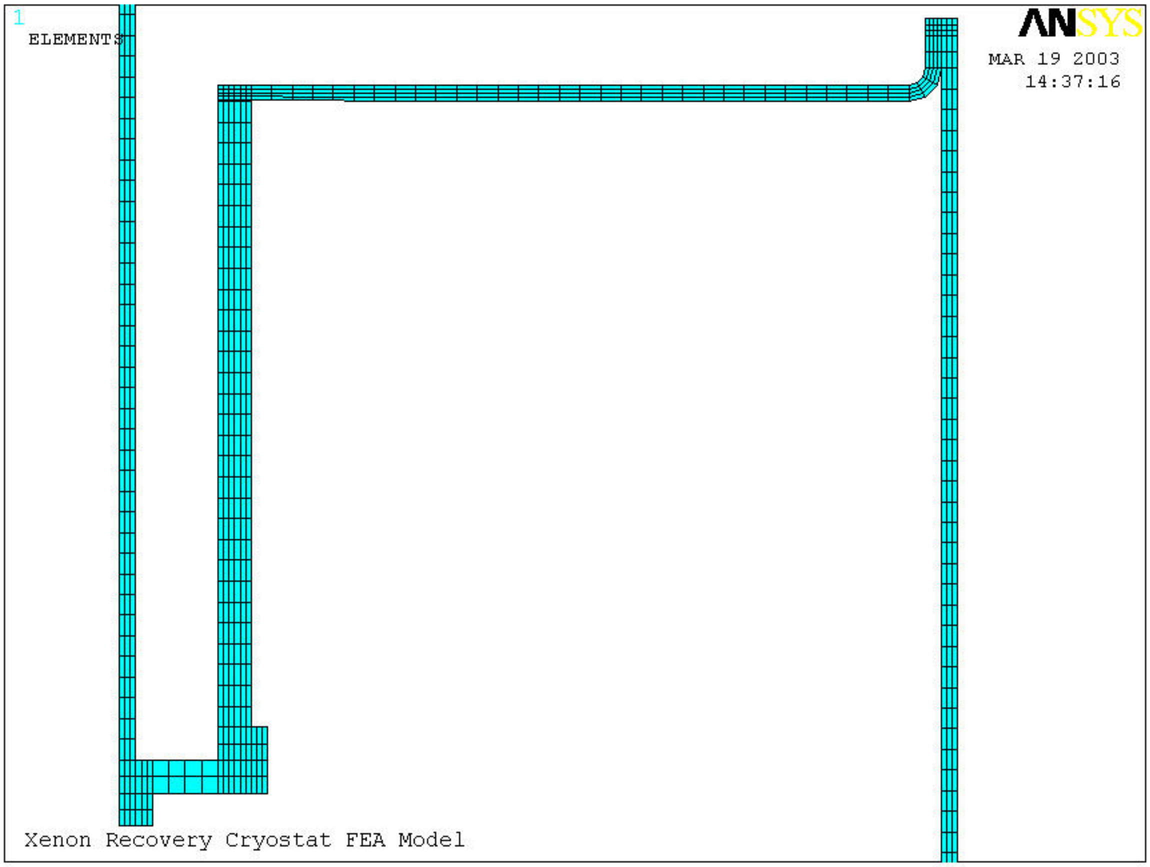
Discussion:

An FEA analysis has been performed to determine the deflection and stress of the lower disk within the Xenon Gas Recovery Cryostat for the PHENIX project.

Analysis Method and Assumptions:

An axi-symmetric model was chosen using a mapped mesh of plane 82 elements. The vessels were artificially shortened since the stresses in these areas were not a concern. However the top and bottom endcaps were modeled to distribute the pressure loading correctly to the walls and ultimately the lower disk boundaries. A finer mesh was used in the areas where high stresses were expected.





Element Choice:
PLANE82 is a higher order version of the two-dimensional, four-node element (PLANE42). It provides more accurate results for mixed (quadrilateral-triangular) automatic meshes and can tolerate irregular shapes without as much loss of accuracy. The 8-node elements have compatible displacement shapes and are well suited to model curved boundaries.
The 8-node element is defined by eight nodes having two degrees of freedom at each node: translations in the nodal x and y directions. The element may be used as a plane element or as an axisymmetric element. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.

Large Deflection option ON:
Small deflection and small strain analyses assume that displacements are small enough that the resulting stiffness changes are insignificant.
In contrast, *large strain* analyses account for the stiffness changes that result from changes in an element's shape and orientation. By using this option, you activate large strain effects in those element types that support this feature. The large strain feature is available in most of the solid elements (including all of the large strain and hyperelastic elements), as well as in most of the shell and beam elements. Large strain effects are not available in the ANSYS/Professional program.
The large strain procedure places no theoretical limit on the total rotation or strain experienced by an element. However, the procedure requires that strain *increments* must be restricted to maintain accuracy. Thus, the total load should be broken into smaller steps.

Stress Stiffening option ON:
Stress stiffening (also called geometric stiffening, incremental stiffening, initial stress stiffening, or differential stiffening by other authors) is the stiffening (or weakening) of a structure due to its stress state. This stiffening effect normally needs to be considered for thin structures with bending stiffness very small compared to axial stiffness, such as cables, thin beams, and shells and couples the in-plane and transverse displacements. This effect also augments the regular nonlinear stiffness matrix produced by large strain or large deflection effects.

Non-Linear material Properties:
A bi-linear material property curve for type 304 stainless steel was used:

Strain	Stress
.00130	39,000 psi
.65	87,000

Loads and Boundary Conditions:

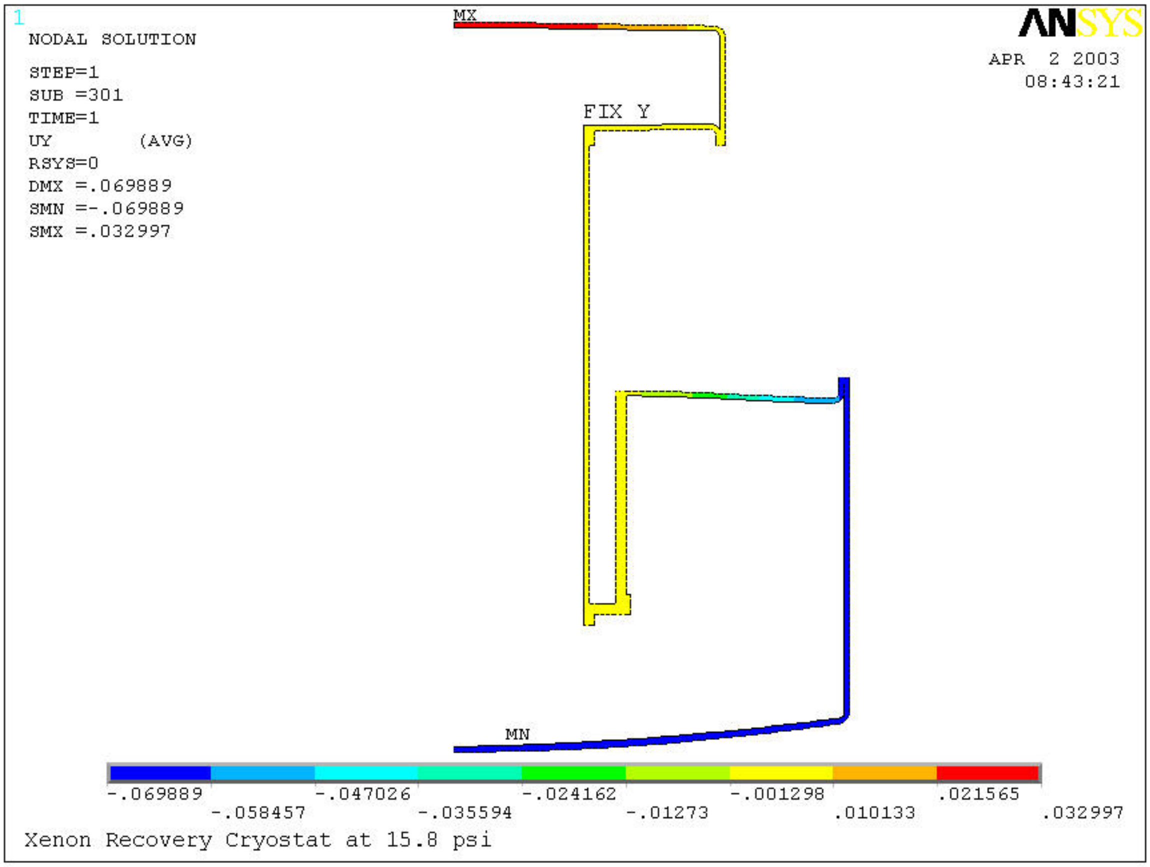
A single point on the inner cylindrical tube was held in the y direction so as to maintain a reference point for deflection in the y direction and to prevent rigid body motion. The centerline of the axi-symmetry was held in the x direction.

A 15.8 psi load was placed on all the walls of the vessel. This load was broken into 100 smaller substeps to allow model solution convergence.

Results / Summary:

The max stress and strains occurred in the lower disk, as expected. The material in the lower disk went slightly above the yield point for the design load condition of 15.8 psi and still further for 2X this load. However, the strain values indicate that it did not approach ultimate stress. No other area of the vessel exceeded or approached yield. Also, the 2X load condition indicates that the areas of peak stress for the design condition are stress relieved, and the peak area shifts from the welded area to the inner bend of the outside radius of the lower disk (See figures below).

For the lower disk:	**at 15.8 psi**	**at 31.6 psi**
Max Deformation (y dir)	.103 inches	.197 inches
Max Stress (Von Mises)	41 ksi	47 ksi
Max Strain (Von Mises)	.0026	.0060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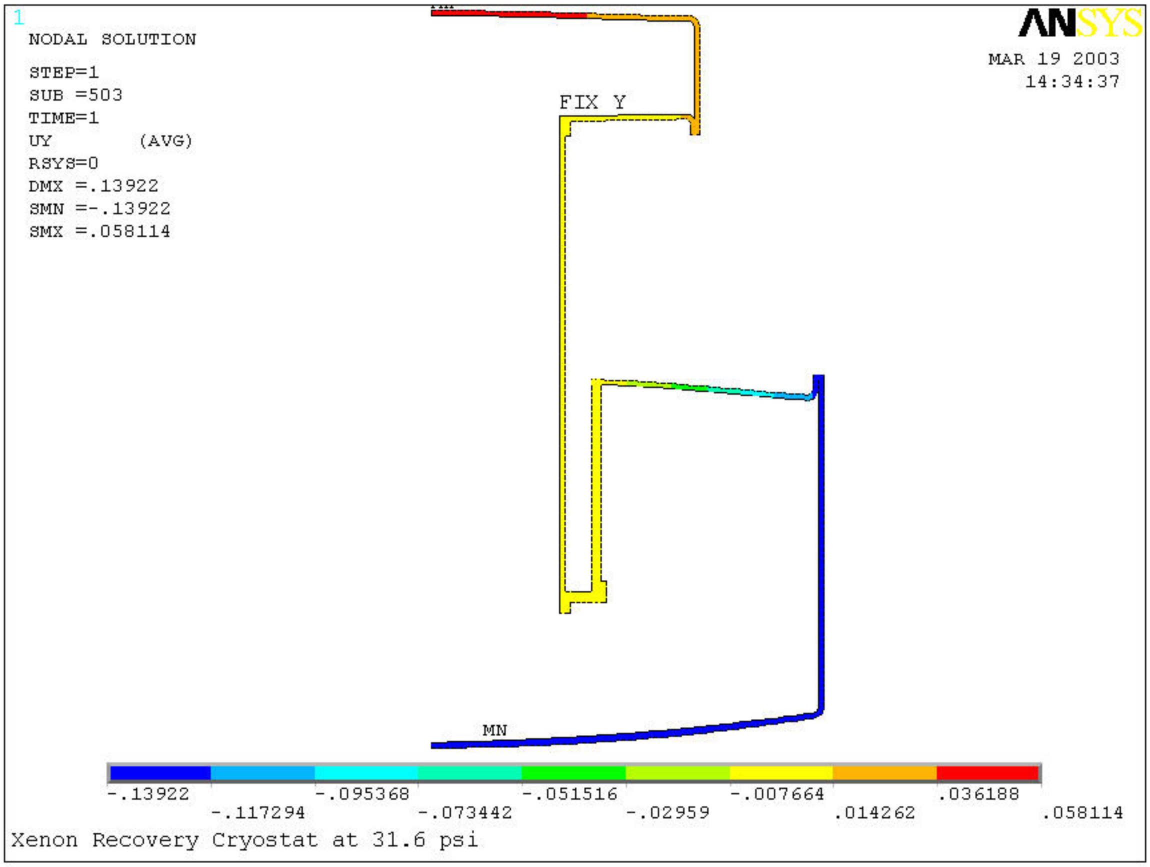
Xenon Recovery Cryostat at 15.8 psi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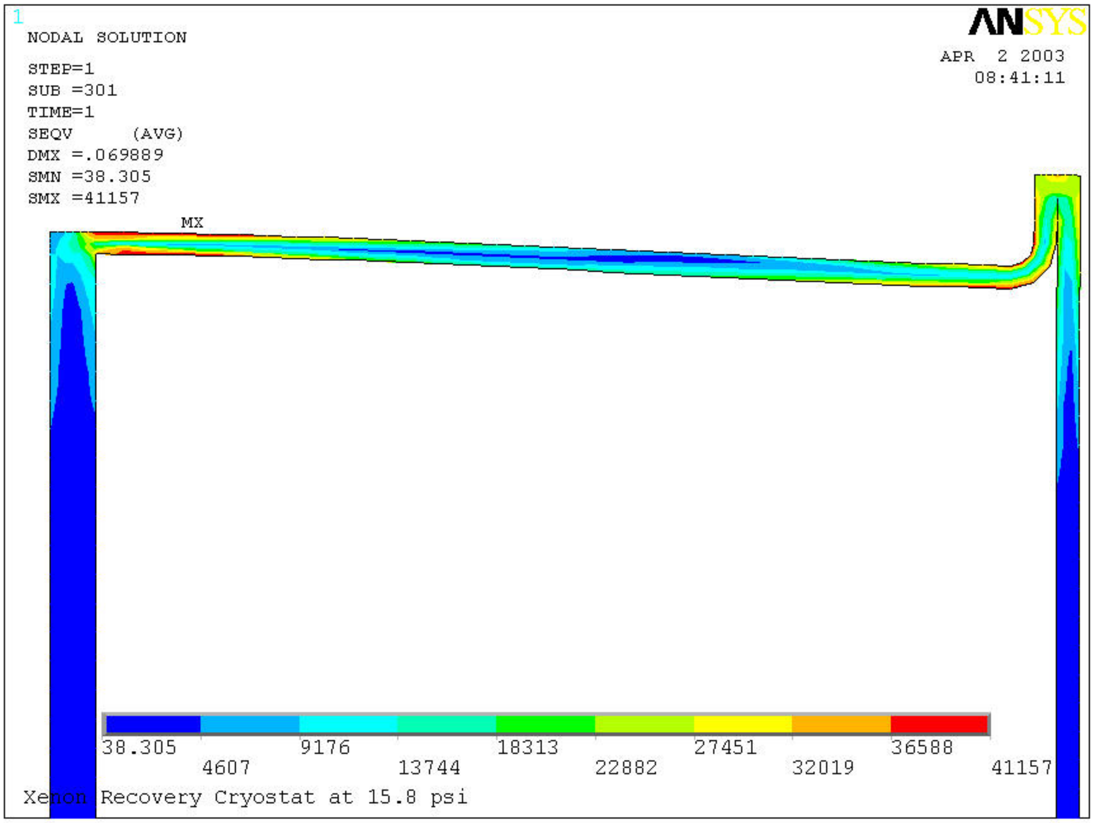
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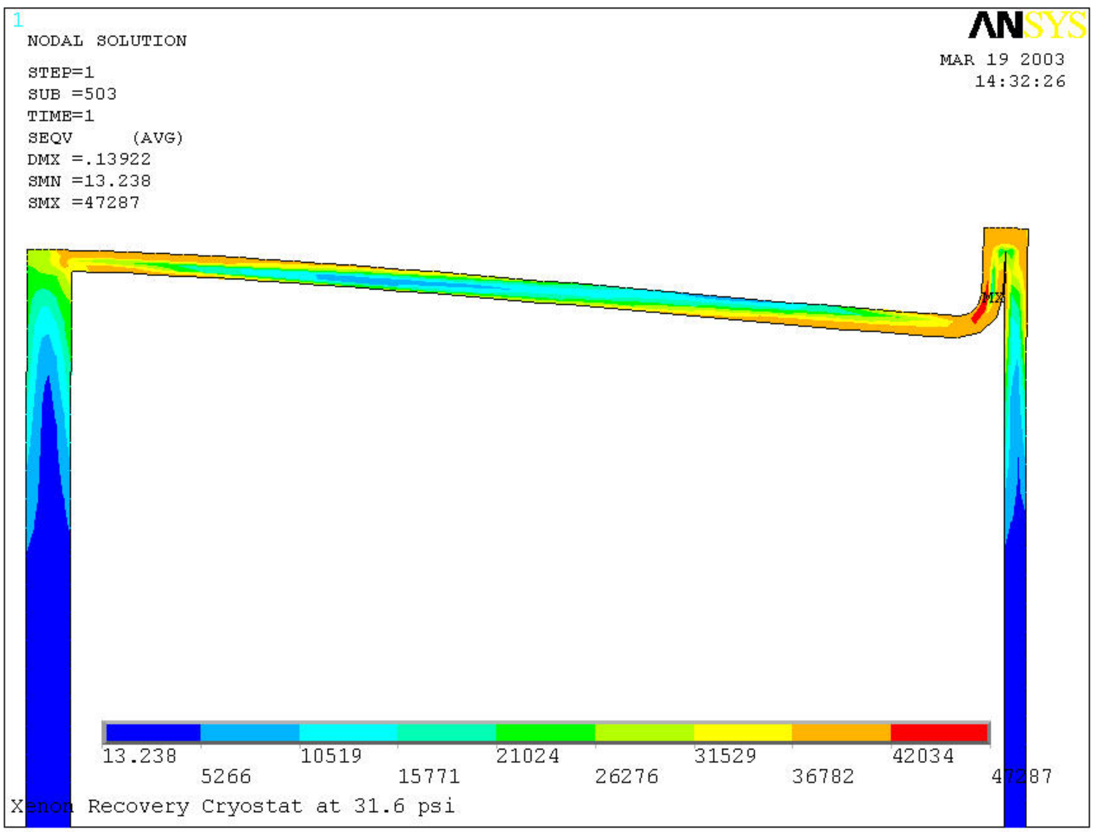
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31529
36782
42034
47287
Xenon Recovery Cryostat at 31.6 psi

Conclusion:

It appears that the disk will yield slightly on first use, but should not experience catastrophic failure. The max stress initially occurs near both welds, but eventually stress-relieves itself in this area through the yielding process, and should remain stable thereafter.

Memorandum

Date: **December 16, 2003**

To: **Yousef Makdisi –** Chair of RHIC Experiment Safety Committee

CC: **Peter Kroon, Steven Kane**

From: **Ed O'Brien –** PHENIX Director of Operations

Subject: **PHENIX Xenon Recovery System**

PHENIX plans to operate the Time Expansion Chamber/Transition Radiation Detector in Run 4 with a gas mixture that has a 45% xenon component. In order to operate the detector in an affordable manner, PHENIX has designed and built a xenon re-circulation and recovery system. The xenon re-circulation and recovery system was reviewed and approved by the BNL Cryogenic Safety Committee on April 3, 2003. We had a final walk–thru of the system by the committee on September 10, 2003. The system has been approved to operate since the last action item was cleared in September. Documents describing the operation of the recovery system can be found at:

> http://www.phenix.bnl.gov/~afranz/xenon/XENONproc.082103.doc
> http://www.phenix.bnl.gov/~afranz/xenon/XENONproc.082103.doc.pdf

During normal operation of the xenon recovery system, custom-made vacuum-insulated cryostats act as cold-traps and fill with liquid xenon. There are two cryostats, which are filled with xenon from the re-circulation system one at a time. Each cryostat takes between 1-2 weeks to fill. Once one cryostat is filled, we switch the flow of the recovered xenon to the second cryostat and prepare to transfer the liquid xenon in the filled cryostat to a steel gas cylinder. In order to make the transfer we must put some pressure on the cryostat to force the liquid xenon into the steel gas cylinder. At the time of the safety review for the xenon gas system, it was believed that one could force the liquid xenon into the steel cylinder with a pressure of 1 psi in the cryostat. Since the cryostat is a two walled vessel with a vacuum between the outer and inner walls, 1 psi on the inner vessel actually puts 15.7 psi differential pressure (psid) inside the inner vessel of the cryostat. This operation mode with up to 15.8 psid pressure has been approved by the Safety Committee.

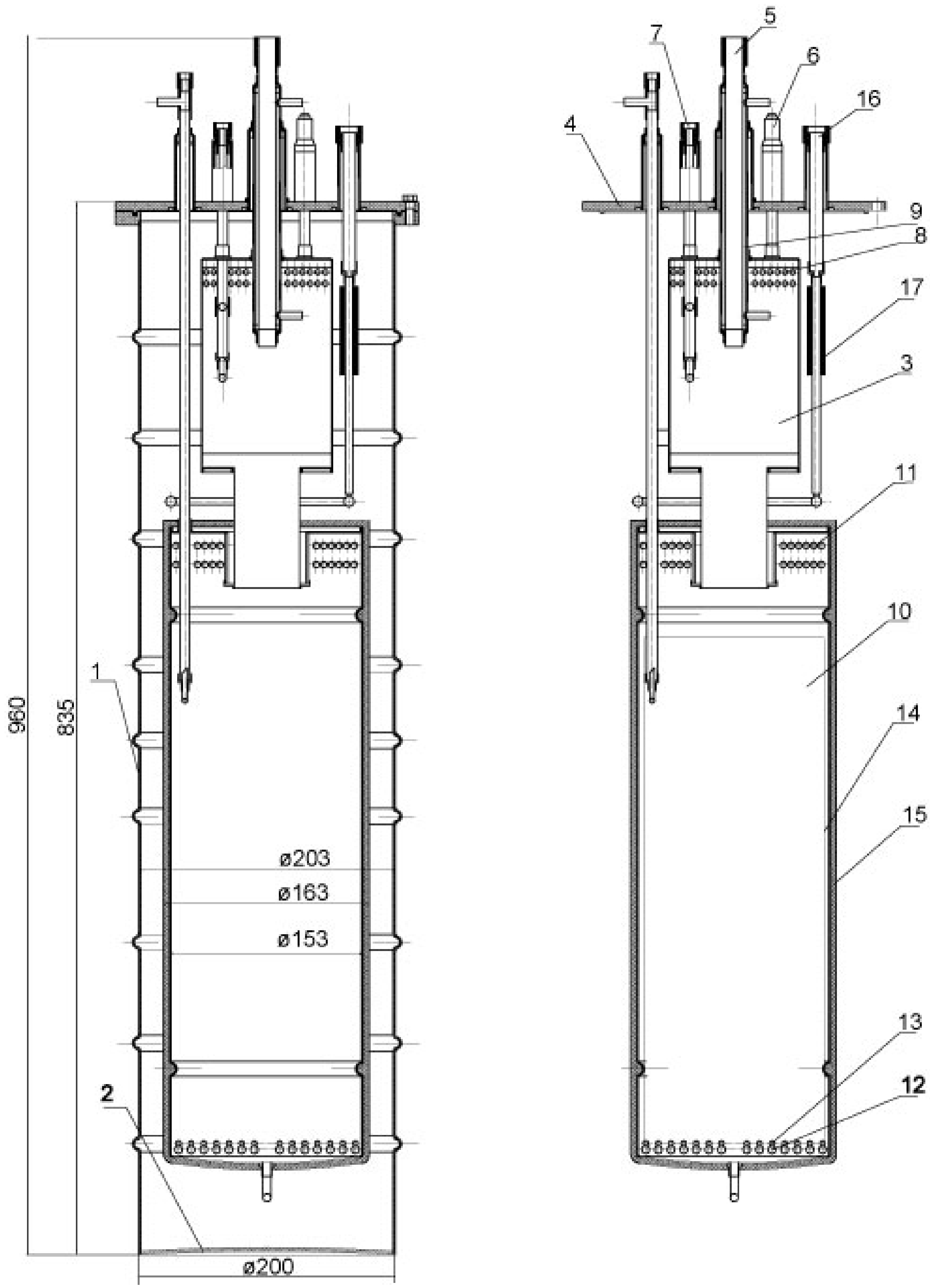
The commissioning of the xenon recovery system in November indicated that we needed to increase the pressure on the liquid xenon in the cryostat from 1 to 10 psi. This would increase the pressure in the inner vessel of the cryostat from 15.7 psid to 24.7 psid. Without this increase in pressure, it is nearly impossible to transfer the liquefied Xenon from the cryostat to the steel gas cylinder.

Our engineers assess that there is no personnel danger associated with this pressure increase, and only minor equipment danger. The inner vessel that will see the increased pressure is completely enclosed by the outer wall of the cryostat, which would serve as a secondary containment wall. In the event of a failure of the cryostat core, the space between the two walls, which is currently at vacuum, would fill with xenon. This space is protected from over-pressure by a 1 psi burst disk. No significant pressure can build up in the cryostat. The equipment risk is damage to cryostat and loss of a few hundred dollars of xenon through venting to the atmosphere.

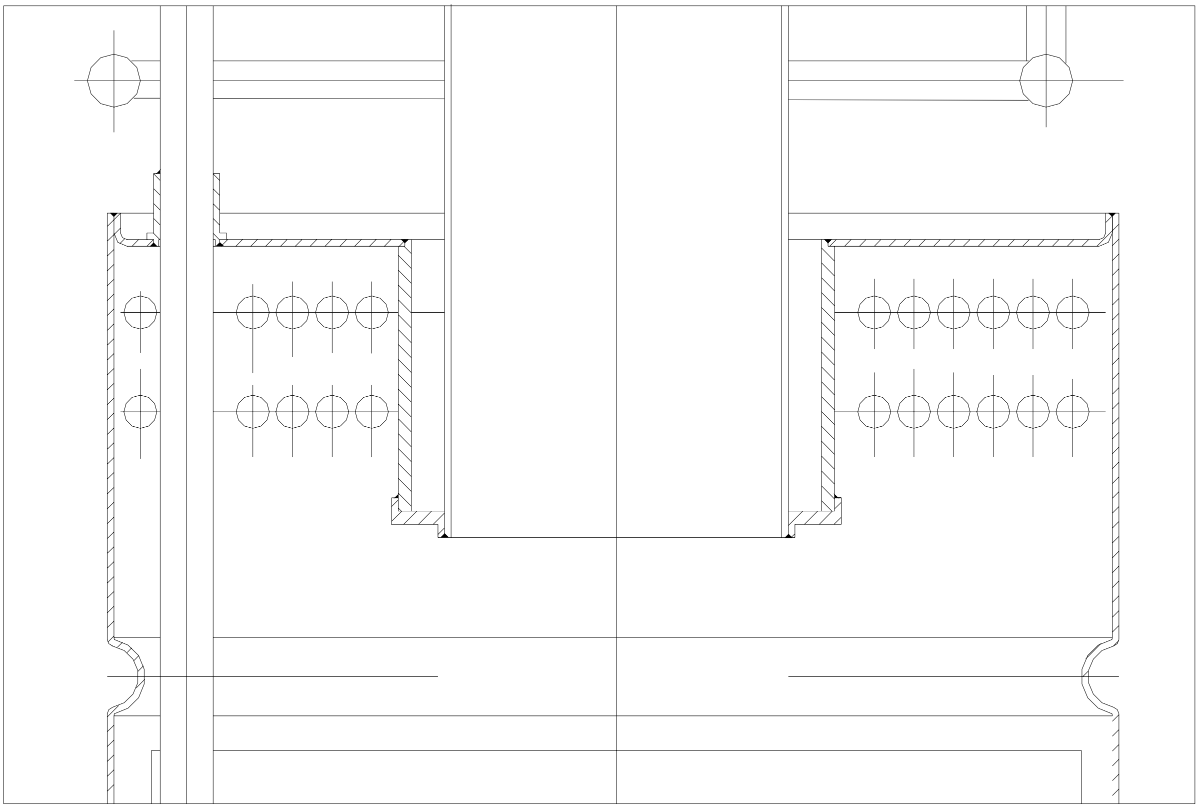
The two xenon recovery vessels have been pressure tested to 2 atms after manufacture. This is 1.19 above the proposed new operating pressure. In addition, a prototype of the inner vessel has been tested to 6.5 atms, or 3.9 times the proposed new operating pressure. The prototype vessel has the material, diameter, end caps and welds all identical to those in the system cryostats. The prototype is shorter than the installed inner vessels. No failures occurred during the tests of either the prototype or actual vessels.

The expense of xenon (~$3.5/liter of gas) makes operating the gas system in re-circulation and recovery mode an imperative. The difference in operating cost between xenon re-circulation/recovery mode, and a single pass system is thousands of dollars a day. PHENIX can not afford to operate the TEC/TRD gas system without recovering the xenon. In addition, the physics program of PHENIX in Run4 makes the operation of this sub-detector with a xenon gas mixture quite important. The identification of high pT electrons in PHENIX relies on the TEC/TRD operating with a xenon-based gas.

PHENIX would like approval to operate the xenon recovery leg of the TEC/TRD gas system at this revised pressure of 10 psig (that is 24.7 psid in the inner vessel). We are willing to perform new over-pressure tests, if requested, on the prototype and xenon recovery vessels at pressures specified by BNL engineers. Because the RHIC schedule is pressing, we would like to come to a resolution of this issue as quickly as possible. We appreciate any effort you can make to help us solve this problem.



<u>Fig.3. Xenon Recovery Cryostat (Xenon Gas Recovery Cryostat 002-0206-913)</u>



Appendix G:

Memo: Xenon Gas Recovery Cryostat Lower Disk Analysis MEMO:

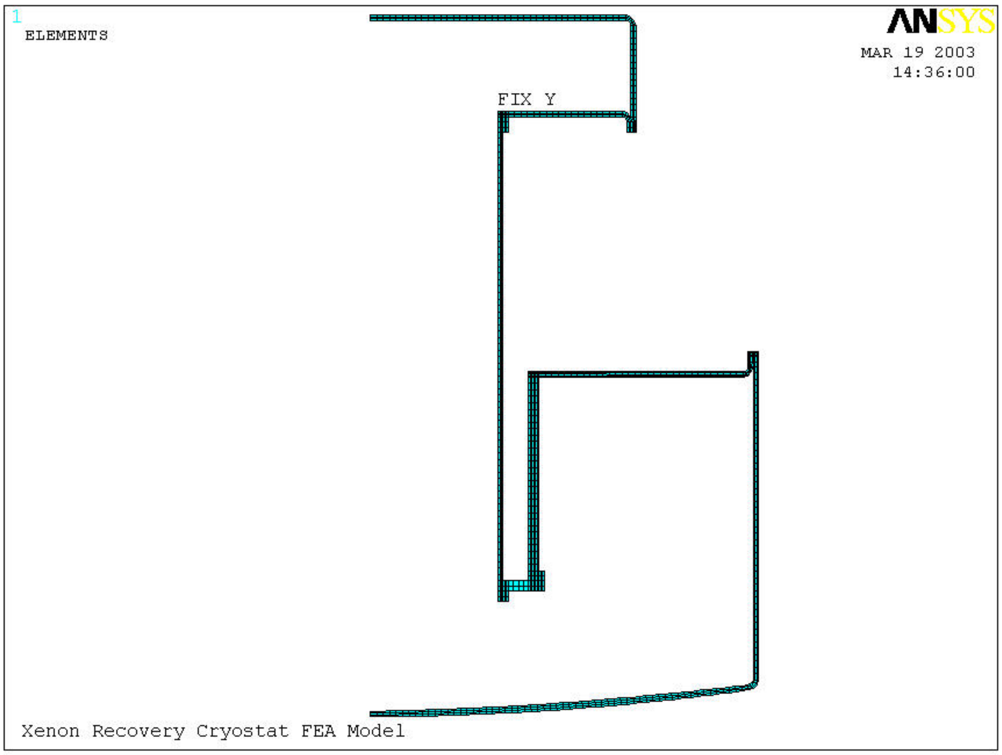
date: April 2nd, 2003
to: P.Kroon
from: S. Bellavia
cc: J. Tuozzolo
subject: Xenon Gas Recovery Cryostat Lower Disk Analysis - revised results

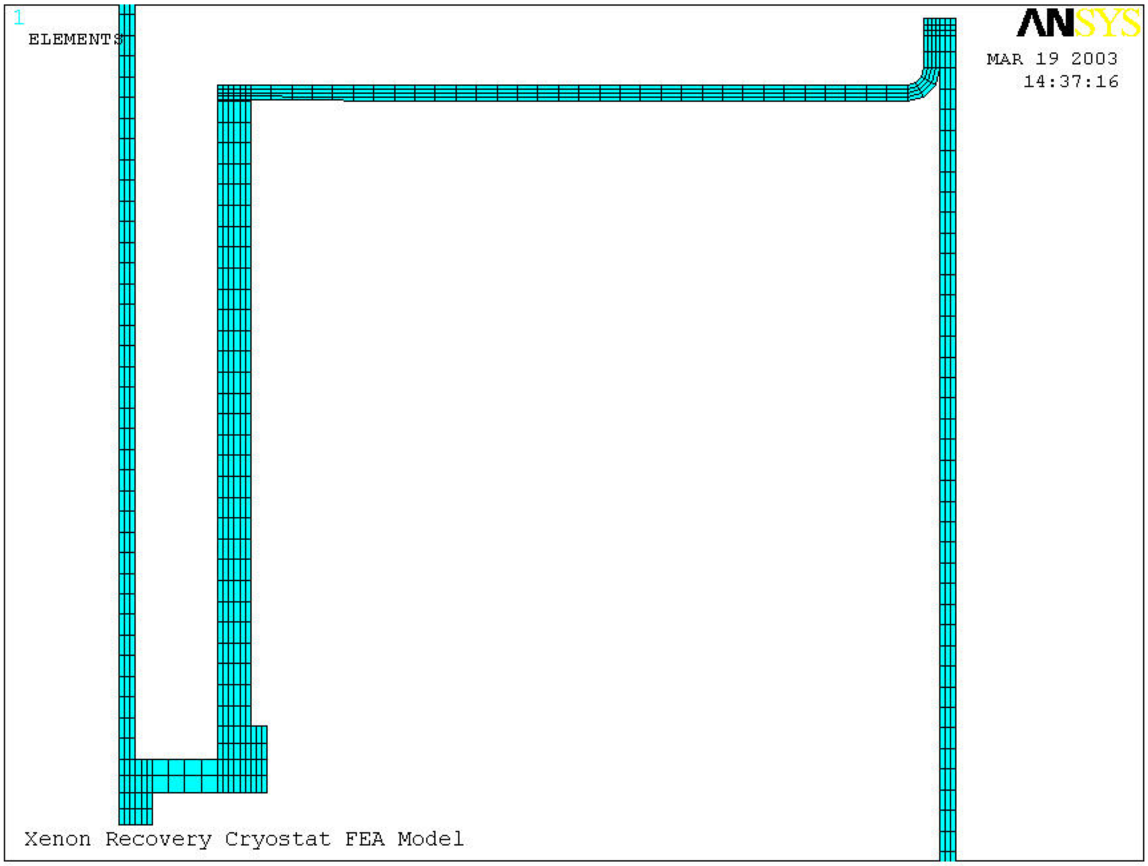
Discussion:

An FEA analysis has been performed to determine the deflection and stress of the lower disk within the Xenon Gas Recovery Cryostat for the PHENIX project.

Analysis Method and Assumptions:

An axi-symmetric model was chosen using a mapped mesh of plane 82 elements. The vessels were artificially shortened since the stresses in these areas were not a concern. However the top and bottom endcaps were modeled to distribute the pressure loading correctly to the walls and ultimately the lower disk boundaries. A finer mesh was used in the areas where high stresses were expected.





Element Choice:
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elements. Large strain effects are not available in the ANSYS/Professional program.
The large strain procedure places no theoretical limit on the total rotation or strain experienced by an element. However, the procedure requires that strain *increments* must be restricted to maintain accuracy. Thus, the total load should be broken into smaller steps.

Stress Stiffening option ON:
Stress stiffening (also called geometric stiffening, incremental stiffening, initial stress stiffening, or differential stiffening by other authors) is the stiffening (or weakening) of a structure due to its stress state. This stiffening effect normally needs to be considered for thin structures with bending stiffness very small compared to axial stiffness, such as cables, thin beams, and shells and couples the in-plane and transverse displacements. This effect also augments the regular nonlinear stiffness matrix produced by large strain or large deflection effects.

Non-Linear material Properties:
A bi-linear material property curve for type 304 stainless steel was used:

Strain	Stress
.00130	39,000 psi
.65	87,000

Loads and Boundary Conditions:

A single point on the inner cylindrical tube was held in the y direction so as to maintain a reference point for deflection in the y direction and to prevent rigid body motion. The centerline of the axi-symmetry was held in the x direction.

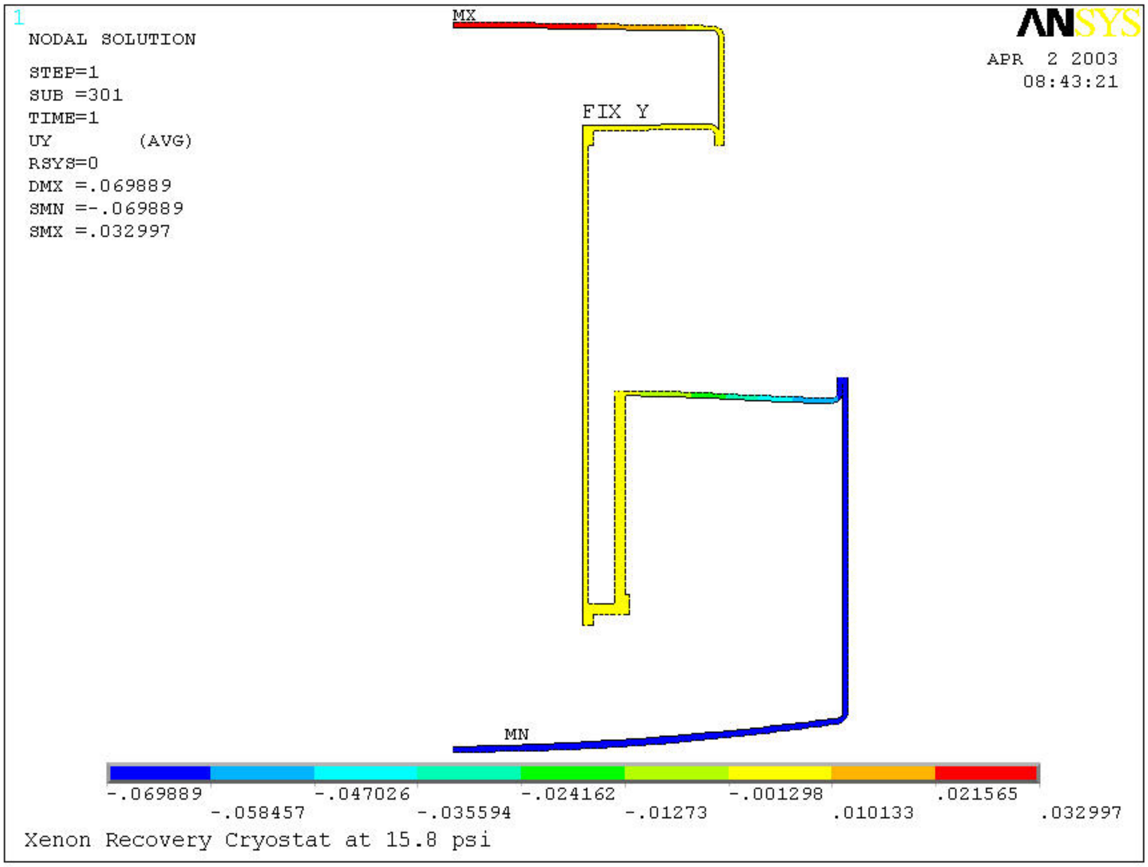
A 15.8 psi load was placed on all the walls of the vessel. This load was broken into 100 smaller substeps to allow model solution convergence.

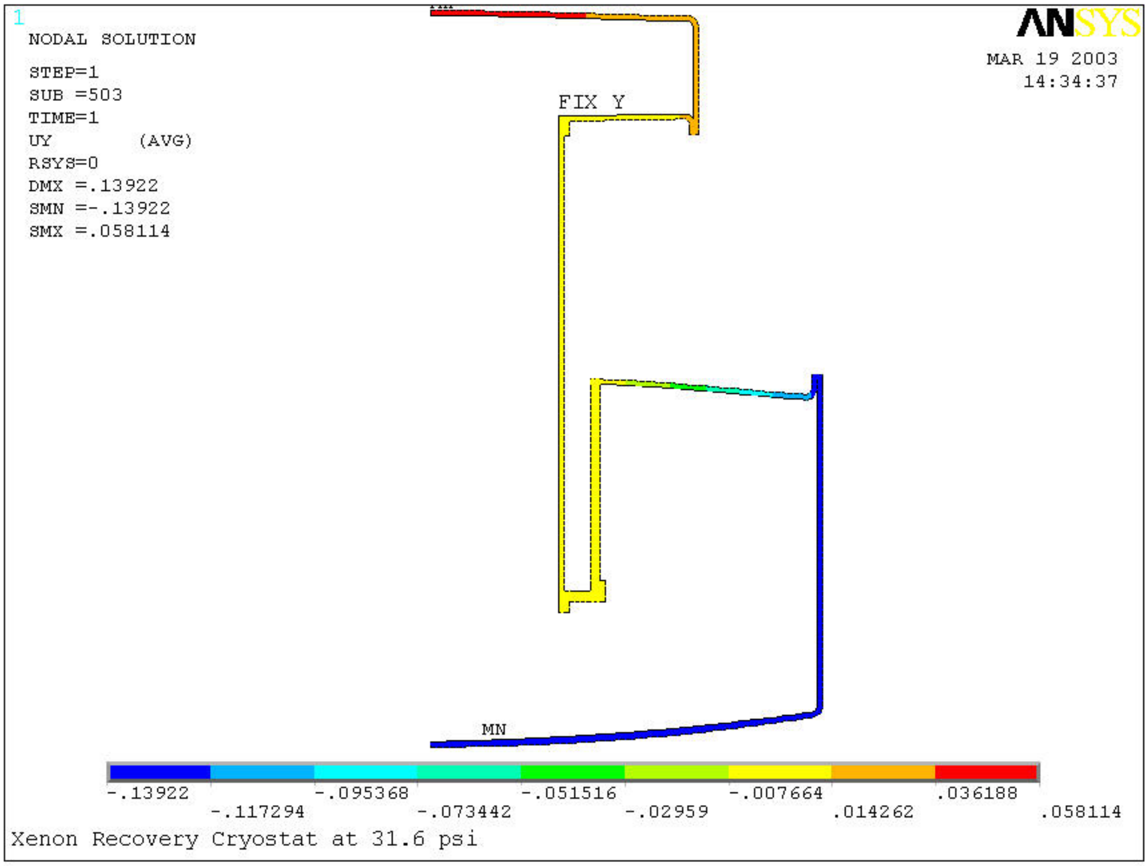
Results / Summary:

The max stress and strains occurred in the lower disk, as expected. The material in the lower disk went slightly above the yield point for the design load condition of 15.8 psi and still further for 2X this load. However, the strain values indicate that it did not approach ultimate stress. No other area of the vessel exceeded or approached yield. Also, the 2X load condition indicates that the areas of peak stress for the design condition are stress relieved, and the peak area shifts from the welded area to the inner bend of the outside radius of the lower disk (See figures below).

For the lower disk: **at 15.8 psi** **at 31.6 psi**

Max Deformation (y dir)	.103 inches	.197 inches
Max Stress (Von Mises)	41 ksi	47 ksi
Max Strain (Von Mises)	.0026	.0060

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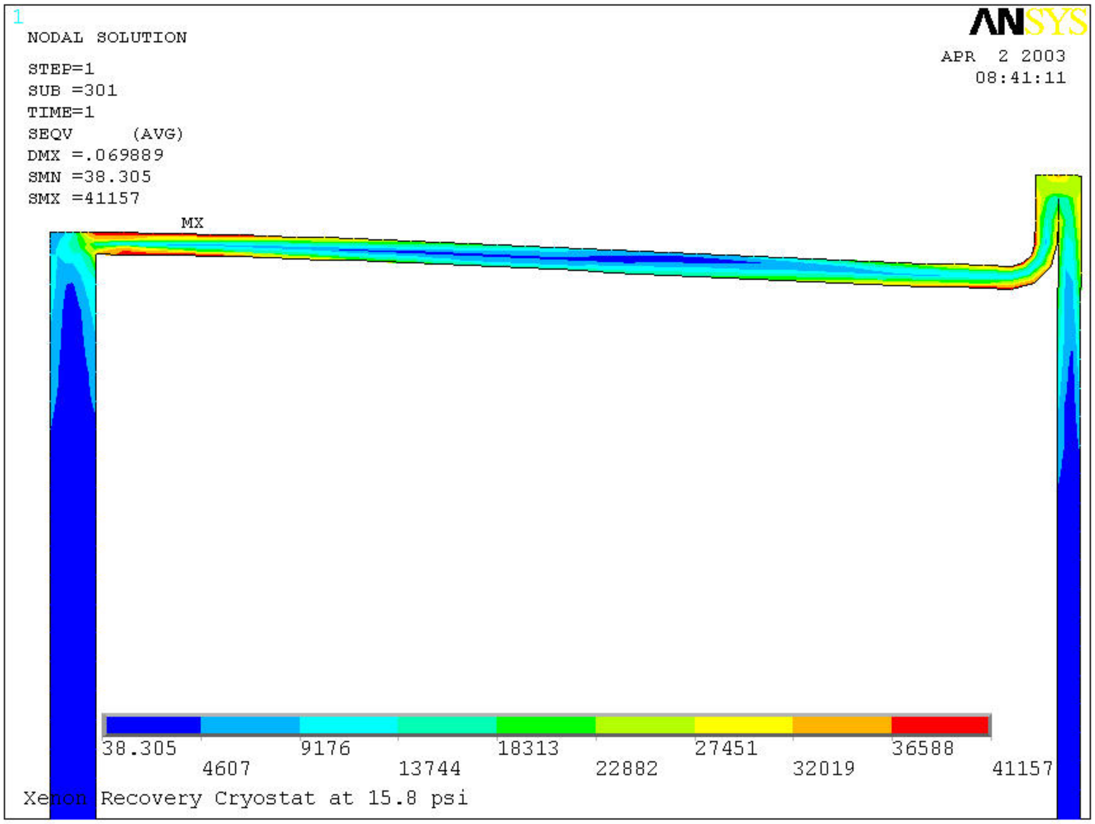
Xenon Recovery Cryostat at 31.6 psi



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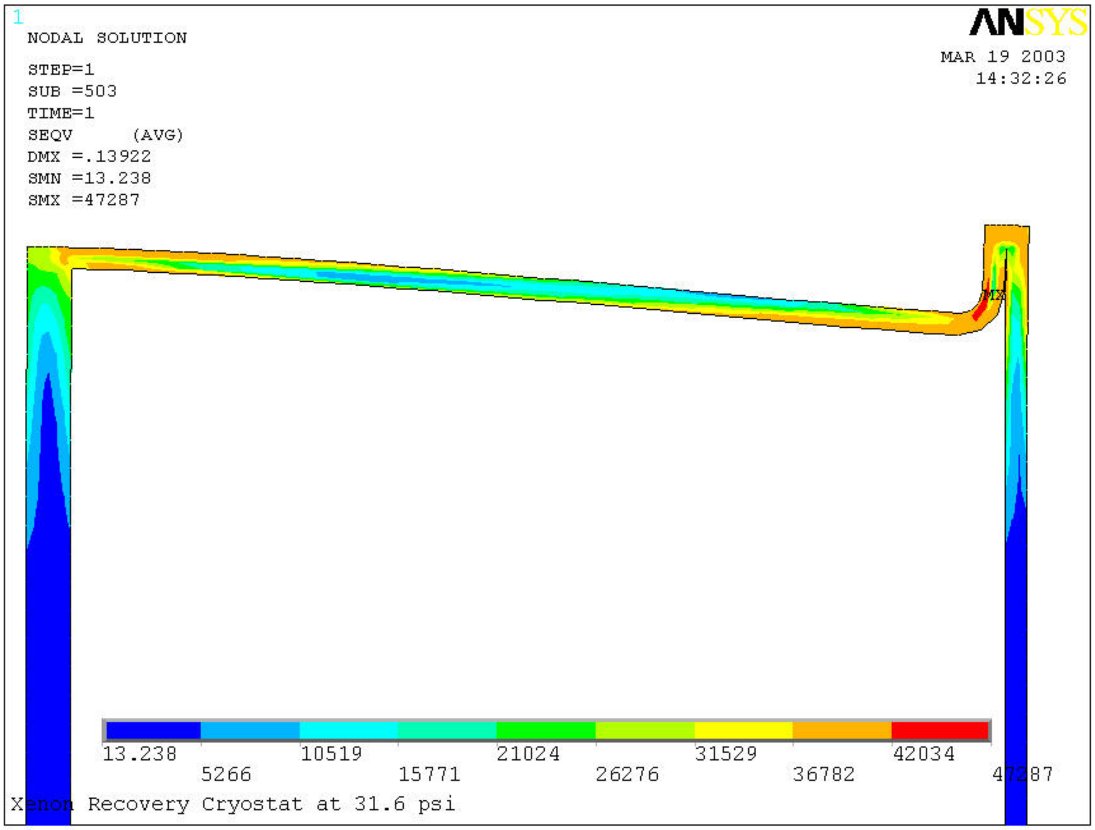
41157
Xenon Recovery Cryostat at 15.8 psi



Conclusion:

It appears that the disk will yield slightly on first use, but should not experience catastrophic failure. The max stress initially occurs near both welds, but eventually stress-relieves itself in this area through the yielding process, and should remain stable thereafter.

Summary:

10 liter cryogenic vessel with pressure relief to atmosphere fully contained in an insulating vacuum vessel. Vacuum vessel protected by 1 psig relief.

Located on PHENIX outdoor gas pad - no ODH issues

During normal operation, inner vessels operate at TEC/TRD vent pressure (~0 psig). Experience during commissioning shows that xenon transfer process requires a higher pressure (<10 psig).

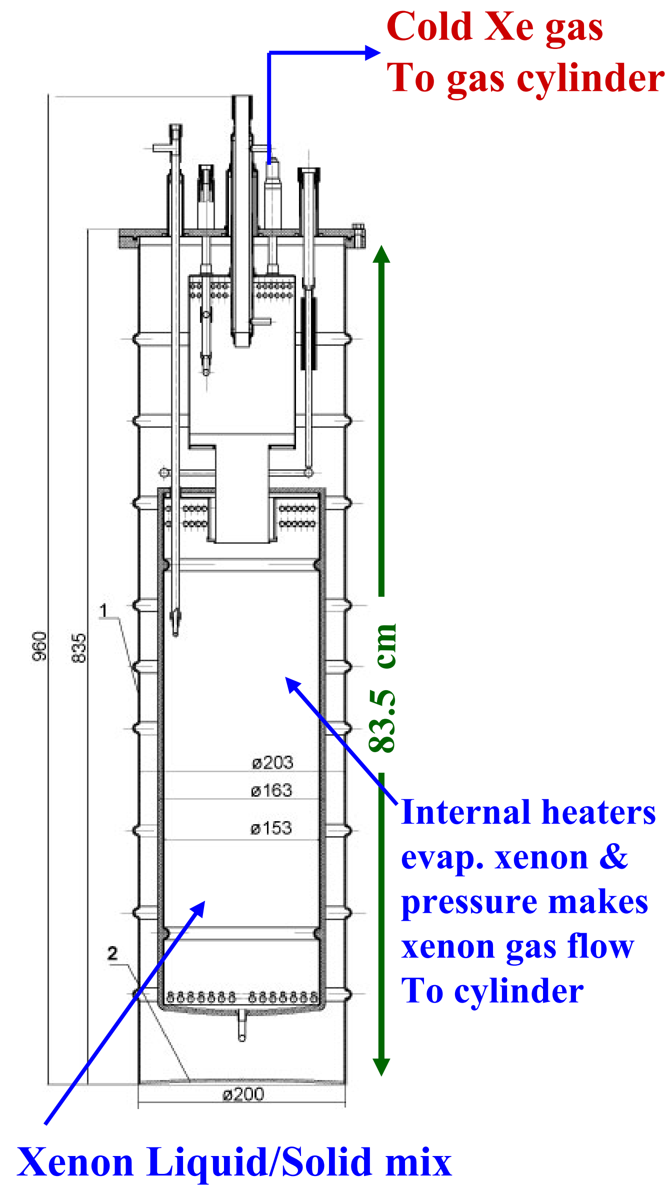
Mechanical model fabricated for pressure test tested to 96 psig without failure, though expected yielding is evident.

Results of failure of inner vessel should be fully contained within vacuum vessel, resulting in loss of vacuum and pressure differential on inner vessel. The vacuum vessel relief could come into play to prevent any over-pressure on the vacuum vessel (net vacuum volume> xenon volume). There is no personnel hazard.

PHENIX Xenon Recovery System

- PHENIX Xenon Re-circulation and Recovery System was reviewed by BNL Cryo Safety Committee 4/03/03.
- Final system walk-thru 9/10/03.
- All action items were cleared & the system was approved for operation.

- Recovery system contains two cryostats for liquid xenon capture.
- Every 1-2 week a full cryostat must be drained of xenon into steel gas cylinder bottle.
- CSC approved 1 psi gas pressure (15.7 psid) to be used to pressure the xenon to flow to gas cylinder
- Commissioning of system established that we need <u>maximum</u> 10 psi gas pressure (24.7 psid) to enable the xenon to flow into gas cylinder.
- Request approval to operate in this mode after appropriate stress tests have been performed



Lessard, Edward T

From: Lessard, Edward T

Sent: Tuesday, December 23, 2003 4:04 PM

To: Makdisi, Yousef I; Travis, Richard J; 'Mike Iarocci'; Glenn, Joseph W; Kane, Steven F; Wu, Kuo-Chen

Subject: RE: Xenon Vessel Pressure Test

Hi Yousef:

Thanks for the follow-up. It seems to be very sturdy. However, I suggest we reconsider our finding after the Cryogenic Safety sub-committee meets in mid-January. At that time, I am hoping the sub-committee would be able to document a standard approach toward approving this class of vessel.

Regards.

Ed

-----Original Message-----
From: Makdisi, Yousef I
Sent: Tuesday, December 23, 2003 3:42 PM
To: Travis, Richard J; Lessard, Edward T; 'Mike Iarocci'; Glenn, Joseph W
Cc: Makdisi, Yousef I
Subject: FW: Xenon Vessel Pressure Test

Gentlemen,
I am forwarding the pressure test results from Charlie Pearson to those who were in the review. In light of this, and that this represents some 15 fold the operating pressure, I would like to ask the committee to reconsider the finding that PHENIX come for another review before operating next year.

Regards,
Yousef (ESRC Chair)

-----Original Message-----
From: Pearson, Charles E
Sent: Tuesday, December 23, 2003 3:13 PM
To: Pisani, Robert; Biggs, John C; Kroon, Peter J
Cc: Makdisi, Yousef I; Kane, Steven F; Tuozzolo, Joseph E
Subject: Xenon Vessel Pressure Test

The sample pressure vessel was hydrostatically tested by Charles Bloxon and the writer.

Using a 0- 400 PSI gage with 5 PSI divisions:
The pressure was successfully increased from 50 PSIG to 400 PSIG in ~25 PSI increments. Each incremental step was held for 10 to 15 seconds

Using a 0 – 5000 PSI gage with 100 PSI divisions:
The pressure was increased from 400 PSI to 1000 PSI in ~50 PSI increments. Each incremental step was held for 10 to 15 seconds. At 1000 PSI the pressure dropped due to a small break in the weld on the top of the vessel.